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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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ABSOLUTE ELECTROACOUSTIC MEASUREMENT OF TEMPERATURE OSCILLATIONS IN SUPERFLUID HELIUM BY THE RECIPROCITY METHOD

by

Bradley Ray Ogg
and
James Valdivia Jr.

December 1983

Thesis Advisor S. L. Garrett

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Absolute Electroacoustic Measurement of Temperature Oscillations in Superfluid Helium by the Reciprocity Method

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Submitted in partial fulfillment of the
requirements for the degree of

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An experiment will be described which has verified for the first time an extension of the reciprocity calibration technique to reversible thermal transducers in superfluid helium. A plane-wave resonator of circular cross-section was capped at both ends by reversible teflon slit-electret diaphragms to generate or detect thermal waves. The resonator also incorporated a heater and a d.c.- biased carbon resistance thermometer to set independent upper and lower limits on the thermal excursions within the resonator. The temperature excursions measured by the reciprocity method fell between the upper and lower limits, which, for lower modes, were separated by only a few percent. For higher modes, the lower limit departed from the upper limit due to the thermal inertia of the resistance thermometer, but the reciprocity result remained only a few percent below the upper bound set by the thermophone over nearly a decade in frequency. The "slit-electret" transducers had sensitivities in excess of 100 V/^{0}K, and temperature oscillations as small as 10^{-10} ^{0}K/(Hz$^{1/2}$) were detected.

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I. INTRODUCTION

A. CLASSICAL RECIPROCITY

Before addressing the subject of this thesis, the extension of the acoustical reciprocity technique to thermal (second) sound in superfluid helium, it will be useful to review the development of the classical technique which has been central to the progress of acoustical science over the last forty years. The specific extension of these ideas to the calibration of second sound transducers in superfluid helium will be treated in chapter II.

1. Reciprocity Relations

In applying the Reciprocity Theorem for the absolute calibration of microphones, MacLean [Ref. 1] and independently Cook [Ref. 2], have demonstrated that it is possible to determine the absolute sensitivity of an electroacoustic transducer by making only electrical measurements, without reference to a primary acoustic standard.

To illustrate the technique, consider the linear, passive, four-pole network of Figure 1.1.

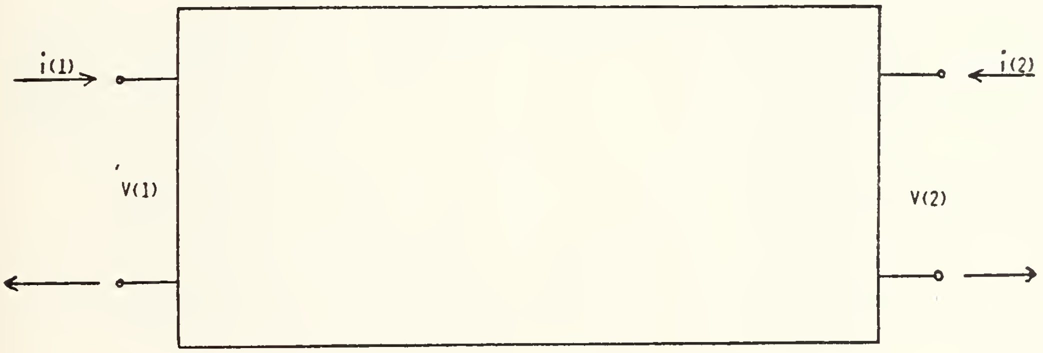

Figure 1.1 A Linear Passive Four-Pole Network.

The system response can be described by the following pair of linear equations,

$$V(1) = a\ i(1) + b\ i(2) \qquad \text{(eqn 1.1)}$$

$$V(2) = c\ i(1) + d\ i(2)\ . \qquad \text{(eqn 1.2)}$$

The above network, whether it serves to model an acoustical, electrical, mechanical, electroacoustical or electromechanical system, will satisfy the Reciprocity Theorem whenever

$$b = \pm c.$$

Capacitive microphones were used in this experiment; therefore, for our purposes, $b = +c$ in equations 1.1 and 1.2 [Ref. 3]. If we let our network model an electroacoustic system consisting of two reversible transducers (Figure 1.2) then,

$$V(1) = a\ i(1) + b\ i(2) \qquad \text{(eqn 1.3)}$$

$$V(2) = b\ i(1) + d\ i(2)\ . \qquad \text{(eqn 1.4)}$$

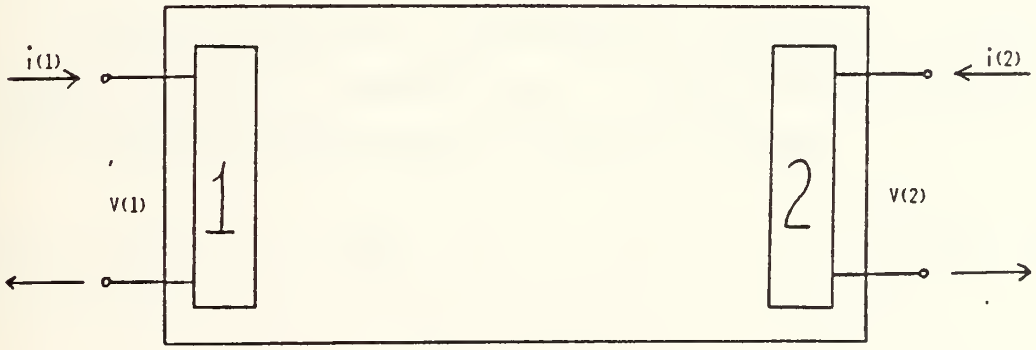

Figure 1.2 Transducers 1 and 2 Coupled by an Acoustic Field.

It should be noted that equation 1.4 represents the receiver, or microphone, side of our network, while equation 1.3 represents the source, or speaker. Also note that $c = b$ must exist since our transducers are electrostatic devices.

For continued compatability with existing literature concerning the Reciprocity Theorem by Rudnick [Ref. 4] and Swift [Ref. 5], the notation of MacLean [Ref. 1] will also be used in this report:

M = Sensitivity as a microphone

S = Strength as a Source

therefore,

$$Mo = \text{open circuit volts/pressure at mic} \qquad \text{(eqn 1.5)}$$

$$Ms = \text{short circuit current/pressure at mic} \qquad \text{(eqn 1.6)}$$

$$So = \text{pressure at mic/current into speaker} \qquad \text{(eqn 1.7)}$$

$$Ss = \text{pressure at mic/volts across speaker} . \qquad \text{(eqn 1.8)}$$

When transducer 1 is used as a speaker driven by a voltage $V(1)$ and a current $i(1)$, and when transducer 2 is short circuited, equations 1.3 and 1.4 become

$$V(1) = a\ i(1) + b\ i(2) \qquad \text{(eqn 1.9)}$$

$$0 = b\ i(1) + d\ i(2) \qquad \text{(eqn 1.10)}$$

which leads to

$$V(1)/i(2) = b - (ad/b) . \qquad \text{(eqn 1.11)}$$

Zero appears at the left side of equation 1.10 because transducer 2's output terminals have been short circuited.

When the same short circuit measurements are again made on our network, but with the roles of the transducers reversed, we find that equations 1.3 and 1.4 now yield

$$0 = a\ i(1) + b\ i(2) \qquad \text{(eqn 1.12)}$$

$$V(2) = b\ i(1) + d\ i(2) \qquad \text{(eqn 1.13)}$$

which leads to

$$V(2)/i(1) = b - (ad/b) . \qquad \text{(eqn 1.14)}$$

From equations 1.11 and 1.14 we see that

$$V(2)/i(1) = V(1)/i(2) , \qquad \text{(eqn 1.15)}$$

which is the Helmholtz/Rayleigh statement of the Reciprocity Theorem [Ref. 6]. By equations 1.6 and 1.8

$$i(2) = P(2)\ Ms(2) \qquad \text{(eqn 1.16)}$$

$$P(2) = V(1)\ Ss(1) \qquad \text{(eqn 1.17)}$$

therefore

$$i(2) = V(1)\ Ss(1)\ Ms(2) \qquad \text{(eqn 1.18)}$$

and

$$[V(1)/i(2)] = [Ss(1)\ Ms(2)]^{-1} . \qquad \text{(eqn 1.19)}$$

Similarly

$$[V(2)/i(1)] = [Ss(2)\ Ms(1)]^{-1} . \qquad \text{(eqn 1.20)}$$

Using equation 1.15 we obtain

$$Ss(2)\ Ms(1) = Ss(1)\ Ms(2) \qquad \text{(eqn 1.21)}$$

which finally leads to

$$Ms(2)/Ss(2) = Ms(1)/Ss(1) . \qquad \text{(eqn 1.22)}$$

When a similar analysis is performed, using equations 1.5 and 1.7 (microphone output terminals open) we see that [Ref. 1],

$$\begin{aligned} Mo(1)/So(1) &= Mo(2)/So(2) \\ &= Ms(2)/Ss(2) \\ &= Ms(1)/Ss(1) . \qquad \text{(eqn 1.23)} \end{aligned}$$

Therefore, the ratio of a transducer's sensitivity as a microphone to it's strength as a source is dependent only on the properties of the space through which the sound must propagate. It should be noted that no mention of resonator geometry has been made, and in fact, the above ratios are independent of the physical aspects of the resonator [Ref. 4], or any other geometric boundary condition.

If we let both transducers be identical and ideal[1] then $Mo(1) = Mo(2)$ and we can define

$$Mo/So = 1/Z \qquad \text{(eqn 1.24)}$$

where "Z" is the quantity which characterizes the acoustic geometry, and has the units of acoustical impedance.

From the open circuit receiver case where $i(1)$ is used to drive side 1 and the output of side 2 is $V(2)$, then equations 1.5 and 1.7 yield

$$V(2)/i(1) = So(1)\ Mo(2)\ . \qquad \text{(eqn 1.25)}$$

Multiplying the right side of equation 1.25 by $(Mo(2)/Mo(2))$ and using equation 1.24 yields

$$V(2)/i(1) = Z\ (Mo)^2 \qquad \text{(eqn 1.26)}$$

or

$$Mo = [V(2)/(i(1)\ Z)]^{1/2}\ . \qquad \text{(eqn 1.27)}$$

---

[1] The transducer is small compared to a wavelength of sound and is so non-compliant that, as a microphone, it's presence at a point within the sound field will never affect the sound pressure at that point. When used as a speaker it's volume velocity is independent of the acoustical load.

This says that once the acoustical impedance Z is determined, the absolute sensitivity of our identical and ideal transducer can be calculated from equation 1.27.

2. Acoustical Transfer Impedance

To investigate the parameter Z we first drive the ideal transducer of side 1 with voltage V(1) and current i(1). A volume velocity U(1) will appear at the speaker and

$$V(1) = a\ i(1) + B\ U(1) \qquad \text{(eqn 1.28)}$$

$$P(1) = B\ i(1) + D\ U(1) = 0 \qquad \text{(eqn 1.29)}$$

where P(1) is the pressure at the source. Here, P(1) must be equal to zero since no external pressure is being applied to transducer 1 and the ideal source cannot "feel" it's own generated pressure. With transducer 2 as the short circuited microphone we find

$$V(2) = a\ i(2) + B\ U(2) = 0 \qquad \text{(eqn 1.30)}$$

$$P(2) = B\ i(2) + D\ U(2) \qquad \text{(eqn 1.31)}$$

where P(2) and U(2) are the pressure and volume velocity.

From equations 1.28 to 1.31 it is clear that

$$V(1)/U(1) = B - (aD/B) \qquad \text{(eqn 1.32)}$$

$$P(2)/i(2) = B - (aD/B)\ . \qquad \text{(eqn 1.33)}$$

Therefore, we obtain the following ratios

$$P(2)/i(2) = V(1)/U(1) \quad . \qquad \text{(eqn 1.34)}$$

Utilizing equations 1.6, 1.8 and 1.24 results in

$$Z = P(2)/U(1) = S(1)/M(1) \quad . \qquad \text{(eqn 1.35)}$$

Therefore, Z represents the acoustical transfer impedance (units = gm/cm^4-sec) relating the acoustic pressure at the microphone to the volume velocity at the speaker.

3. Reciprocity Calibration

With the parameter Z now defined by equation 1.35 it is possible to use equation 1.27 to determine our ideal transducer sensitivities. The parameter Z takes on a variety of forms depending on the geometry of the resonator [Ref. 4]. For the plane-wave resonator of figure 1.3 equation 1.27 becomes

$$Mo = [V(m)/(i(s)\ Z)]^{1/2} \quad . \qquad \text{(eqn 1.36)}$$

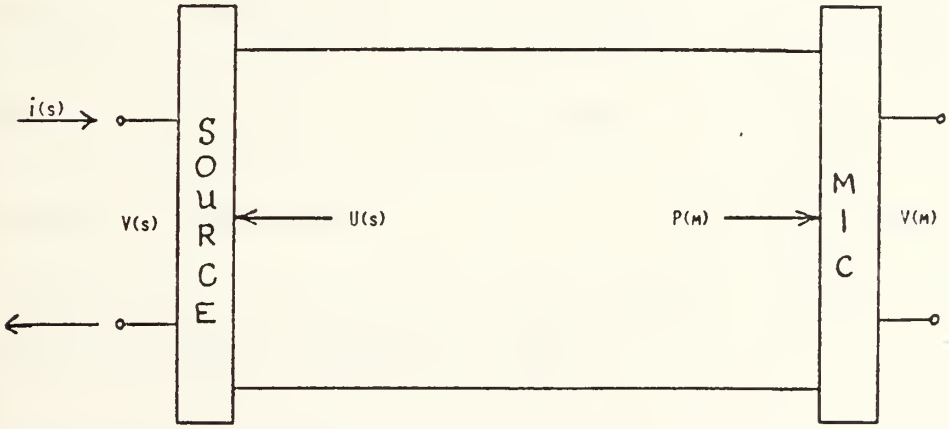

Figure 1.3 Plane-wave Resonator.

TABLE I

Notation for Determining Z

variable	meaning
A	cross-sectional area
C	sound speed
E	energy
f	frequency of n-th mode
ρ	medium density
L	resonator length
n	mode number
P	pressure (rms)
Q	quality factor
V	velocity (rms)

The determination of the acoustical transfer impedance Z for our resonator, using the notation of Table I, is as follows:

$$E(\text{stored}) = \langle KE(\max) \rangle = 1/2\ (\rho A L V^2) \qquad \text{(eqn 1.37)}$$

and since $P = \rho C V$ and $L = nC/2f$ then,

$$E(\text{stored}) = (nAP^2/4\rho Cf) \qquad \text{(eqn 1.38)}$$

and since power radiated is the product of the in-phase pressure and volume velocity, then

$$E(\text{lost/cycle}) = PU/f\ . \qquad \text{(eqn 1.39)}$$

By definition [Ref. 7],

$$Q = 2\pi\, E(\text{stored})/E(\text{lost per cycle}) \qquad \text{(eqn 1.40)}$$

then we have

$$Q = (P/U)(An\pi/2\rho C) \ . \qquad \text{(eqn 1.41)}$$

Combining equations 1.35 and 1.41 yields [Ref. 4],

$$Z = (2\rho CQ)/(An\pi) \qquad \text{(eqn 1.42)}$$

By direct substitution of equation 1.42 into equation 1.27 we finally obtain a viable method of establishing the absolute sensitivities of our ideal transducers:

$$Mo = 10^{-7/2}[\,(V(m)/i(s))(An\pi/2Q\rho C)\,]^{1/2} \qquad \text{(eqn 1.43)}$$

The factor $10^{-7/2}$ occurs if the electrical parameters are in units of volts and amps and the mechanical parameters are in cgs units.

So the acoustical transfer function Z can be determined using both measured values of Q and A as well as the a priori quantities ρ and C. Armed with this information, we can now use equation 1.43 to conduct a calibration of our transducers using the Reciprocity Theorem.

The reciprocity calibration requires two sets of measurements to be taken on the acoustical plane-wave resonator of Figure 1.4. The dimensions of the transducers T, S and M and the lateral dimensions of the resonator are small compared to the acoustic wavelength.

The actual resonator of our experiment consisted of a brass body and "slit" electret transducers. More will be said about our experimental resonator in chapter III.

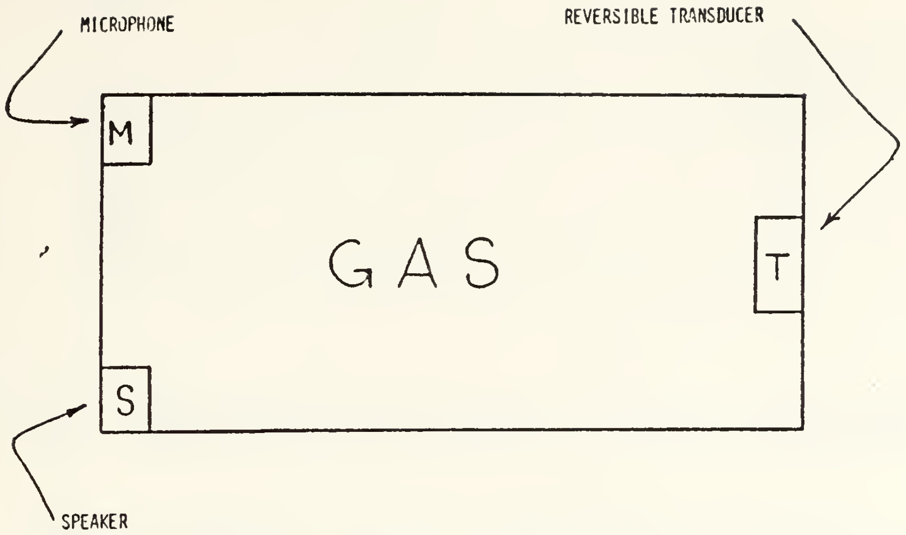

Figure 1.4 Plane-wave Resonator for Reciprocity Calibration.

For the first set of measurements, the reversible transducer T is driven at a resonant frequency of the chamber. The driving voltage V(1) and current I(1) are measured and again, as in equations 1.28 and 1.29, the system response is

$$V(1) = a\ i(1) + B\ U(1)$$

$$0 = B\ i(1) + D\ U(1)\ .$$

The open circuit voltage V(m) at receiver M, used here only as a microphone, is also recorded (refer to Figure 1.5). This voltage corresponds to the pressure P at the ends of the chamber. From equation 1.35 we know

$$P = Z\ U(1)\ . \qquad \text{(eqn 1.44)}$$

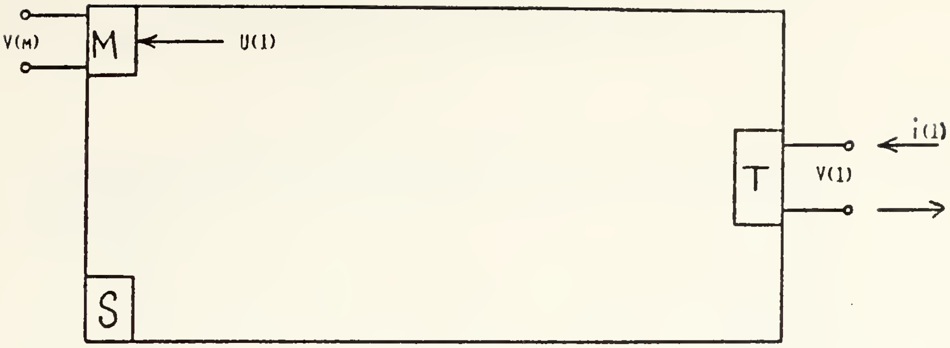

Figure 1.5   Reciprocity Calibration: first measurement set.

For the second set of measurements (refer to Figure 1.6) speaker S is driven with sufficient current i(s) to again produce V(m) at receiver M. This now ensures that the acoustic pressure P has been reproduced within the chamber. The short circuit current i(2) is measured first, giving us equations 1.30 and 1.31

$$0 = a\ i(2) + B\ U(2)$$

$$P = B\ i(2) + D\ U(2)\ .$$

Finally, the open circuit voltage V(2) is measured resulting in,

$$V(2) = B\ U(3) \tag{eqn 1.45}$$

$$P = D\ U(3) \tag{eqn 1.46}$$

where U(3) is the volume velocity which corresponds to the "open circuit" voltage at the receiver T.

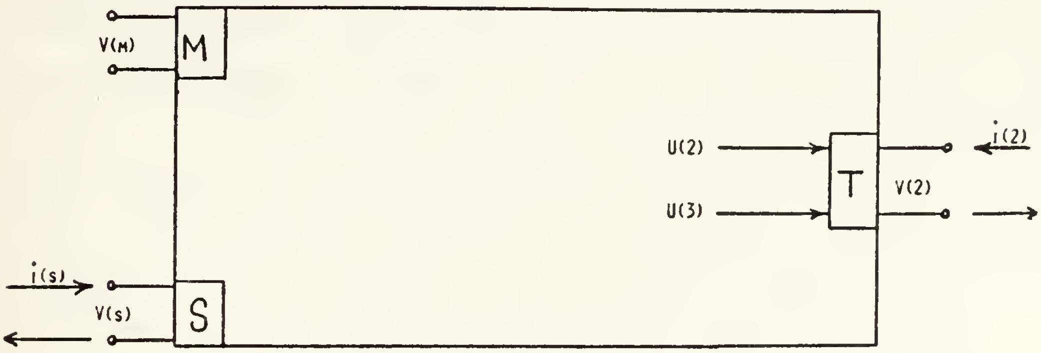

Figure 1.6 Reciprocity Calibration: second measurement set.

The above equations 1.28 to 1.31 and equations 1.44 to 1.46 form a set of seven simultaneous equations in the seven unknown quantities a, B, D, U(1), U(2), U(3), and P. The equations can be combined to yield the following expressions [Ref. 5] for P,

$$P^2 = |V(1)\ i(2)\ Z|$$

$$P^2 = |V(2)\ i(1)\ Z| .$$

Therefore, the sensitivities of microphone M and reversible transducer T are given by the following set of equations (Note that the reciprocity calibration has been accomplished without reference to a primary standard and with only easily obtainable electrical and geometric measurements),

$$\mathrm{Sens}(M) = V(m)/P$$

$$\mathrm{Sens}(T) = V(2)/P .$$

B. HISTORY OF SUPERFLUIDITY

Now for a fundamental look at our experimental medium liquid helium. Probably it's strangest characteristic is its apparent ability to remain in a liquid state, under its own vapor pressure, when temperature is reduced, and with an apparent preference to stay that way right on down to absolute zero. To produce the solid phase requires application of a high pressure, 25 atmospheres or more (Figure 1.7).

The reluctance of helium to solidify results from a combination of two factors: (1) the extremely weak van der Waals force between the atoms and (2) their low mass. The forces are weak because of the simplicity and symmetry of the helium atom with its closed shell of two electrons and the absence of dipole moments for its nucleus. The effect of the low mass is to ensure a high value of zero-point velocity. To see this, consider an atom in the liquid as a free particle located in a small "cage" formed by the adjacent atoms.

The total zero-point energy per mole of the lowest state is then [Ref. 8] $(Nh^2/8m)(4\pi/3V)^{2/3}$, where m is the mass of the atom, V is the molar volume of the cage, h is Planck's constant and N is Avogadro's number. At absolute zero the total energy of the liquid is just the sum of the potential and zero-point energies, and London's [Ref. 8] estimate for this zero-point energy (assumed to be the same for both solids and liquids) indicates that it is lowest at a molar volume of approximately $30 cm^3$. London then showed that at such a volume liquid helium has a lower energy then it does as a solid; therefore, it is in a stable form as a liquid at absolute zero.

Helium has the lowest boiling point of all known substances. For He^4 it is 4.2 °K at STP. Between this temperature and 2.172 °K this liquid behaves like an

ordinary fluid. But as the temperature is lowered it transforms into a second fluid phase which exhibits very different dynamical properties.

During early experimentation it was found that a plot of the specific heat of liquid helium versus temperature indicated a sudden discontinuity at a temperature of about $T_\lambda = 2.17\ ^oK$. This temperature is often called the lambda temperature due to the similarity of the shape of the specific heat curve to the Greek letter "lambda". There is an abrupt change in all the properties of liquid helium at the lambda-point. This change is known as the lambda transition. A very important point to be brought out at this time is that the region above the lambda-point is referred to as helium I (He I) and the region below as helium II (He II).

The difference in behavior is visibly apparent when observing a dewar vessel of liquid He^4 which is cooled through the lambda-point by boiling under reduced pressure. In the He I region, the liquid is greatly agitated by bubbles of vapor which form throughout the liquid and eagerly escape the surface. Yet, immediately as the lambda-point is passed, the liquid becomes extremely calm and no more bubbles are formed. Below the transition temperature the liquid refuses to boil. As pointed out earlier, liquid helium has many unusual properties, one of which is a very high thermal conductivity and this is the cause for the absence of boiling below the lambda-point. If a bubble forms below the surface of the liquid, the pressure inside the bubble must be greater than the vapor pressure above the surface by an amount equal to the hydrostatic pressure head plus the surface tension pressure. Vapor at this increased pressure cannot be formed from the liquid unless the temperature of the fluid below the surface is higher than the temperature at the surface.

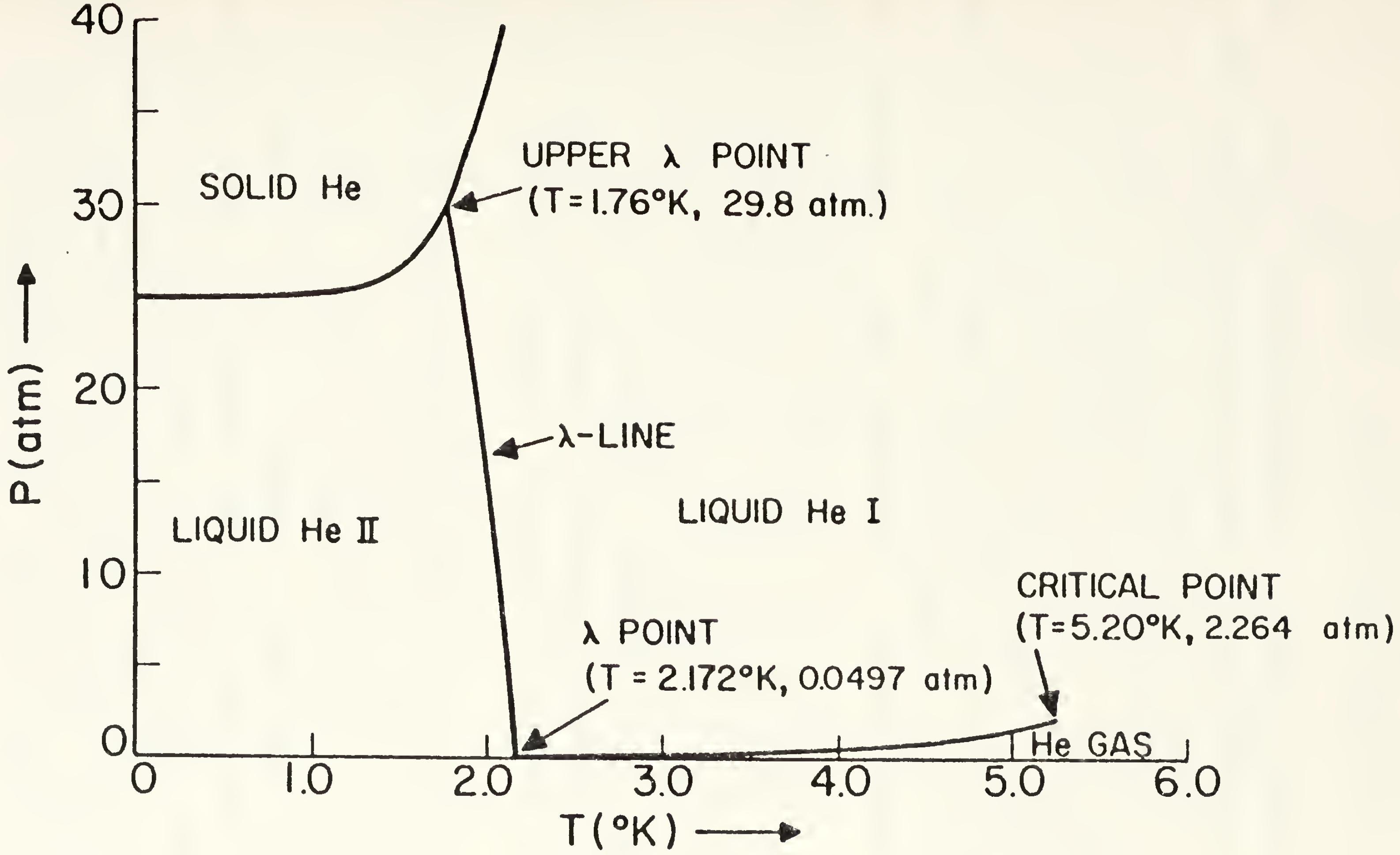

Figure 1.7 Phase Diagram of He⁴.

The thermal conductivity of He II is so large that such a temperature gradient cannot be set up, and so the boiling (agitation) is prevented and all of the evaporation takes place at the surface.

That something strange happens to liquid helium below this lambda temperature was also noticed by Kamerlingh Onnes as early as 1911 [Ref. 9]. He found that when the liquid was cooled below this mysterious temperature it starts expanding instead of continuing to contract, thus deviating from the behavior of most substances. Almost 30 years later Allen and Misener [Ref. 10] and Kapitza [Ref. 11] found that at these low temperatures liquid helium could flow through narrow capillaries (about 10^{-4}cm in diameter) with no measureable resistance. This observation led Kapitza to refer to the liquid as a "superfluid".

Superfluid seems an appropriate name for this unique substance since measurements of flow have been made of He II passing through very fine cracks and extremely narrow slits and capillaries, which for normal liquids are, in effect, impassable. Liquid helium can overcome such obstacles freely even without requiring a noticeable pressure difference, and, strangely enough, it seems to leave its entropy behind.

The superfluid flow phenomenon leads one to question the viscosity of He II. Measurements by Keesom and Ende [Ref. 12] of flow through the aforementioned capillaries seem to indicate that the viscosity of He II is 10^6 times less than that of He I; however, measurements of the viscosity by Keeson and MacWood [Ref. 13] using the rotating disk showed that the viscosity of liquid helium below the lambda-point, although it decreased with decreasing temperature quite considerably, nevertheless varies continuously and is certainly not very different from the viscosity of He I. When Allen/Misener and Kapitza reported their

measurements based on the capillary flow method, it showed the viscosity of liquid helium dropping by many orders of magnitude to an immeasureably small value when the temperature was lowered through the lambda-point. The apparent contradiction between Keesom/MacWood and Allen/Misener and Kapitza is really no contradiction. The former was merely observing the effects of the "normal fluid" component of the helium solution while the latter was observing the affects of the "superfluid" component. This two fluid concept will be discussed in the next section.

Although liquid helium has been used in experimental laboratories for many years as a refrigerant, its unique behavior and unusual properties were not realized until the early 1930's.

One of the most unusal features of He II is that variations of temperature propagate through the liquid not according to the usual Fourier equation, but as a true wave motion whose velocity is independent of the frequency. These temperature waves are entirely analogous to ordinary sound waves, except that the thermodynamic variables are temperature and entropy and not pressure and density. Therefore we can excite temperature waves with a heater in a resonance tube, and pickup standing waves using a thermometer as a detector. This very unusual type of heat propagation is known as second sound [Ref. 14].

A very strange phenomenon was discovered in 1938 by Allen and Jones [Ref. 15]. They were interested in helium conductivity measurements and what they observed was truely unexpected. The experiment consisted of a reservoir and a smaller vessel, both filled with liquid helium and connected by a very fine capillary. The set up is shown in Figure 1.8.

When heat was applied to the inner vessel, they observed that the inner helium level rose slightly above that of the reservoir.

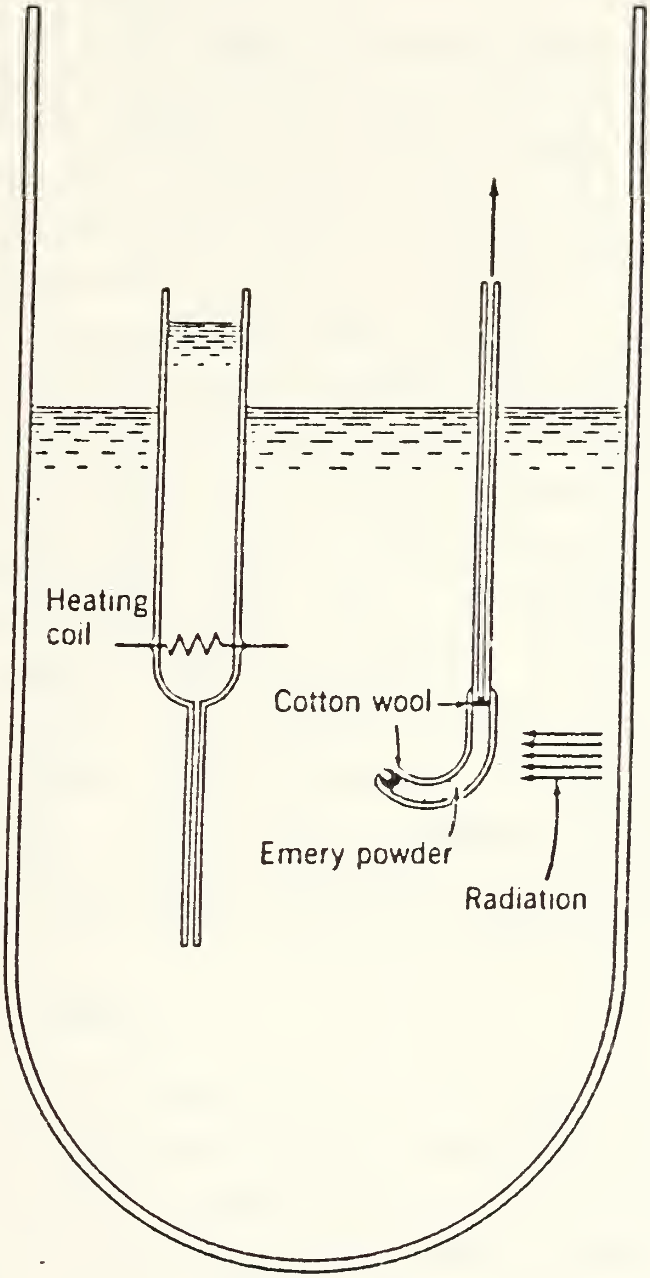

Figure 1.8 Fountain Effect.

In a subsequent experiment, using a narrower inner vessel, they observed a jet of liquid helium rising from the upper end of this narrow vessel to a height of several centimeters. This became known as the "fountain effect", or thermomechanical effect.

What Allen and Jones demonstrated is that you cannot trust intuition to predict the behavior of liquid helium. In the fountain effect, contrary to expectations, the heat current goes in a direction just opposite to the helium current. It would seem that in liquid helium, heat and mass transfer are strongly joined. The inverse of this fountain effect, or the mechanocaloric effect, predicted by Tisza [Ref. 16] and discovered by Daunt and Mendelssohn [Ref. 17], consisted of allowing liquid helium to gravity flow out of its container through a capillary filled with a fine emery powder. As a result, the temperature of the liquid above the capillary rose while the temperature of the liquid helium below the capillary dropped. What this implies is that the liquid which passed through the capillary is different than the bulk liquid in the container from which it came. Again, this alludes to the existance of a two fluid behavior, where one is capable of passage through restricted areas while the other is not, and the thermal properties of these two components are very different.

C. TWO-FLUID MODEL

It should be pointed out at the onset that the phenomenological picture known as the "two-fluid model" is able to correlate the unusual properties of He II with the thermodynamic functions as long as the heat and mass currents are not too large. This requires that we deal with heat fluxes that are linearly proportional to the temperature gradients. Even in this linear region the heat flow is far greater than that observed in other substances.

As mentioned in the previous section, two methods were used to determine the viscosity of He II. One consisted of measuring the viscous resistance to flow (Keesom/Ende) and the other the viscous drag on a body moving in the liquid (Keesom and MacWood). These two methods produced two seemingly different results that would indicate He II is capable of being both viscous and non-viscous at the same time. This apparent contradiction is the basis of the two-fluid model, first suggested by Tisza [Ref. 16]. It is in terms of this model that many of the properties of He II can be explained.

The two-fluid model proposes that helium II behaves as if it were a mixture of two fluids freely intermingling with each other without any viscous interaction. The two parts are referred to as the normal fluid and superfluid components. This does not imply that it is a mixture of two real physical fluids. The liquid is an assembly of He^4 atoms which are all identical, so that it is not possible to regard some atoms as belonging to the normal fluid and the remainder to the superfluid.

The assumptions of the model are very important. Below the lambda-point liquid helium is capable of two different motions at the same time. Each of these has its own 'local' velocity denoted Vn and Vs respectively for the normal fluid and the superfluid. Furthermore, each has its own effective mass density, ρ_n and ρ_s. The total density ρ of the He II is therefore given by

$$\rho = \rho_n + \rho_s \qquad \text{(eqn 1.47)}$$

and the total current density by

$$\bar{J} = \rho_n \bar{V}_n + \rho_s \bar{V}_s \; . \qquad \text{(eqn 1.48)}$$

It is important to note that since the superfluid flow has no viscosity it therefore does not involve dissipation and is truly thermodynamically reversible. The normal fluid flow does have viscosity and undergoes dissipation, but only at a rate proportional to the gradient of its velocity according to Landau and Lifshitz [Ref. 14].

London [Ref. 18] always believed in the macroscopic nature of liquid helium. He drew attention to the fact that the behavior of liquid helium could at least be understood in terms of Bose-Einstein condensation. Simply stated, B-E condensation maintains that at a critical temperature (lambda-point for liquid helium) a *macroscopic* fraction of an ideal quantum gas's molecules condense into the same single partical quantum state (the ground state). This fraction is 100% at T= absolute zero and vanishes at the lambda- point temperature for liquid helium. London hypothesised that liquid helium could in fact fit the *qualitative* features of the B-E condensation mechanism, even though it is not an ideal gas, due to its discontinuity of character at the lambda-point. Tisza stated that the B-E condensed particles correspond to the superfluid component while the remaining excited particles correspond to the normal fluid. Furthermore, a single discrete momentum state would mean that there is no continuous reduction of momentum, which would imply zero viscosity. The normal component then carries all of the entropy and is expected to have a viscosity comparable to that of He I. The fraction of the fluid which is in the superfluid state, ρ_s / ρ, is expected to increase as the temperature is decreased.

It should be clear that this model contains an explanation of the viscosity paradox. In the capillary flow experiment only the superfluid is mobile so the liquid exhibits no viscosity. The damping of the rotating disk was due to the drag exerted by the normal component. The observed

decrease in the damping as the temperature decreased is attributed in part to the decrease in the amount of normal fluid available.

D. FIRST AND SECOND SOUND

That in liquid helium a new kind of wave propagation should be possible, was predicted by Tisza [Ref. 16]. He suggested that there should be the pressure wave of ordinary sound where the two components move in phase with each other. Additionally, there should be another wave in which the motion of the two components are 180 degrees out of phase. This second wave would be a compression wave of entropy accompanied by periodic flucuations of the temperature, and the mass density would remain almost constant. This new wave would have to be excited by periodic heating of the fluid and the consequence would be that entropy density and temperature could be the oscillatory parameters in a wave equation.

For ordinary sound the conservation of mass gives us

$$(\partial \rho/\partial t) + \mathrm{div}\ \bar{J} = 0 \qquad \text{(eqn 1.49)}$$

where $\bar{J}$ is the center of mass momentum (equation 1.48), and from the linearize-inviscid Euler equation of hydrodynamics

$$(\partial \bar{J}/\partial t) + \mathrm{grad}\ P = 0\ . \qquad \text{(eqn 1.50)}$$

Eliminating $\bar{J}$ leads to

$$(\partial^2 \rho/\partial t^2) - \nabla^2 P = 0 \qquad \text{(eqn 1.51)}$$

and for adiabatic processes,

$$(\partial^2 \rho/\partial t^2) - (\partial P/\partial \rho)_S\ \nabla^2 P = 0\ .$$

This is the ordinary sound equation, a wave equation for mass density or pressure wave, where

$$U(I)^2 = (dP/d\rho)_S \qquad \text{(eqn 1.52)}$$

is the square of the ordinary sound velocity.

For the development of the wave equation for thermal waves we follow the derivation of Gogate and Pathak [Ref. 19] but still neglect non-linear terms and confine ourselves once again to the reversible process. Starting with the equation for the conservation of entropy

$$(\partial \rho S/\partial t) + \mathrm{div}(\rho S\ \bar{V}_n) = 0 \qquad \text{(eqn 1.53)}$$

which explicitly contains the assumption that the entropy flow follows the normal fluid.

The kinetic energy density of this two-fluid system can be expressed as

$$E = (1/2)(\rho_n \bar{V}_n^2 + \rho_s \bar{V}_s^2) \qquad \text{(eqn 1.54)}$$

$$E = (1/2\rho)(\rho_n \bar{V}_n + \rho_s \bar{V}_s)^2 + E'' \qquad \text{(eqn 1.55)}$$

where $E'' = (\rho_n \rho_s/2\rho)(\bar{V}_s - \bar{V}_n)^2$.

The term E" is called the kinetic energy of internal convection while the first term is considered to be the kinetic energy of the actual mass transfer.

If work is done reversibly by transferring the heat (Q) from temperature T to (T-dT), the second law of thermodynamics requires that work (W) be expressed as

$$W = (QdT)/T \ .$$

Considering a thin layer of helium of thickness dx in which the temperature varies by dT, the heat current becomes

$$q = \rho ST \bar{V}_n \qquad \text{(eqn 1.56)}$$

and is assumed to propagate perpendicularly through the layer. It carries the heat (qdt) through a square centimeter of the layer in a finite time (dt). As stated earlier, this process must be reversible, therefore the work

$$q(dt)(dT/T) = \rho S \cdot \bar{V}_n \; dT \; (dt)$$

has to be done. Tisza proposed that this work would be required to change the kinetic energy of internal convection (E") per unit area of the layer of thickness dx:

$$dE'' \cdot (dx) = -\rho S \bar{V}_n \; dT \; (dt) \qquad \text{(eqn 1.57)}$$

or

$$dE''/dt = -\rho S(\bar{V}_n \cdot \text{grad } T) \; . \qquad \text{(eqn 1.58)}$$

Due to the fact that the thermal expansion coefficient is so small we can say that for thermal oscillations

$$\bar{J} = \rho_n \bar{V}_n + \rho_s \bar{V}_s = 0 \qquad \text{(eqn 1.59)}$$

and

$$d\rho/dt = 0 \; , \qquad \text{(eqn 1.60)}$$

which yields

$$E'' = (\rho \rho_n / 2\rho_s) \bar{V}_n^2 . \qquad \text{(eqn 1.61)}$$

Substituting equation 1.61 into equation 1.58 we see that

$$(\rho\,\rho_n/\rho_s)\,\overline{V}_n \cdot (d\overline{V}_n/dt) = -\rho S(\overline{V}_n \cdot \text{grad } T) \qquad \text{(eqn 1.62)}$$

or

$$(d\overline{V}_n/dt) + (\rho_s/\rho_n)\,S \text{ grad } T = 0 \, . \qquad \text{(eqn 1.63)}$$

We consider terms like $\overline{V}_n$, grad T, grad S, dS/dt, etc., as small of first order, and neglect products of any two of these quantities. This allows us to eliminate $\overline{V}_n$ in equations 1.53 and 1.63 and get

$$(\partial^2 S/\partial t^2) - (\rho_s/\rho_n)\,S^2 \text{ div(grad } T) = 0 \, . \qquad \text{(eqn 1.64)}$$

When the process occurs at constant pressure then we are left with a very interesting equation which does have a familiar "form",

$$(Cp/T)\,(\partial^2 T/\partial t^2) - (\rho_s/\rho_n)\,S^2 \text{ div(grad } T) = 0. \qquad \text{(eqn 1.65)}$$

This is a wave equation for the temperature. The same equation also holds for the entropy (S). When we compare this equation to that for ordinary sound we are struck by the similarity in format. Therefore, we know that the propagation velocity for these thermal waves can be expressed as

$$U(II)^2 = (\rho_s/\rho_n)[S^2\, T/Cp] \, . \qquad \text{(eqn 1.66)}$$

E. OUTLINE OF EXPERIMENT

This experiment enables us to obtain the absolute sensitivities of thermal transducers, in situ. A cylindrical plane-wave resonator has been constructed which is closed at either end by capacitive porous diaphragm transducers [Ref. 20]. In addition, one end also has an acoustically transparent "spiral web" electrical heater (thermophone) and the other end has a low mass carbon composition electrical resistance thermometer. A figure of the resonator, and its components, is shown below.

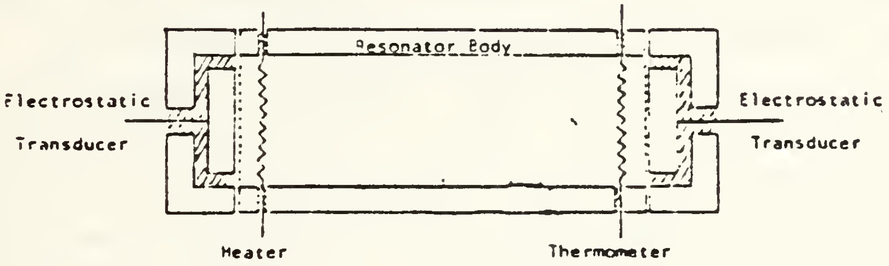

Figure 1.9 Schematic of Experimental Resonator.

At a variety of temperatures the following procedure was used to calibrate one of the three reversible transducers (two electrostatic, one resistive). The transducer to be calibrated (designated R for reversible) will be driven at resonance with current I and used as a speaker. One of the other two reversible transducers will be used as a microphone (M) to determine the resonant frequency f(n) and Q(n) of the n-th plane-wave resonance. Then, while monitoring the output of M, a third transducer will be driven at f(n) until the output of M is again the same value observed when R was being used as the source. In this way the sound field has been recreated. The open circuit voltage of R will then be recorded.

This will be sufficient to determine the sensitivity of R at f(n) from the reciprocity relation and known thermodynamic parameters [Ref. 21]. A comparison of the output voltages of the other two reversible transducers to the now calibrated third transducer will determine their sensitivity. It is then possible to repeat the reciprocity sequence using one of the other reversible transducers and in that way make a "round robin" consistency check. This was done at a variety of temperatures for several plane-wave resonance modes.

To determine whether the reciprocity results are both consistent and absolutely correct, it is necessary to compare the calibrations obtained by the above procedure against a "primary" standard. This is done in two ways:

(1) Knowing the electrical power being generated in the heater and the resonance Q, the theory of superfluidity allows us to calculate the second sound amplitude in the resonator [Ref. 22] if we assume all of the heating (at twice the frequency of the driving current) results in the generation of second sound. Although most of the oscillating energy appears as second sound, a small fraction will leak out along the electrical leads and therefore the sound amplitude obtained in this way will be an upper bound.

(2) The carbon resistor, biased with a constant current source I(b), will generate an oscillating voltage of amplitude

$$\delta V = (dR/dT)\,\delta T\ I(b),$$

where δT is the amplitude of the temperature oscillations generated by the second sound resonance [Ref. 23]. Since (dR/dT) can be determined in a static calibration, the finite frequency effects due to the thermometer heat capacity and thermal conductance and Kapitza resistance will make the sound amplitude measured in this way a lower bound.

The sensitivities of the above transducers are expected to fall within the upper and lower bounds if the reciprocity method is correct. We will show in chapters IV and V that these bounds form a fairly close ceiling and floor limitation on these sensitivities.

II. THEORY

A. INTRODUCTION

The principle of reciprocity was first introduced into acoustics by Rayleigh in 1873 when he derived the reciprocity relation for a system of linear equations and gave "a few examples [to] promote the comprehension of a theorem which, on account of its extreme generality, may appear vague" [Ref. 6]. He cited physical examples in acoustics, optics and electricity and credited Helmholtz with a derivation of the result in a uniform, inviscid fluid in which is immersed any number of rigid, fixed solids, pointing out that the principle "will not be interfered with" even in the presence of damping. The first physical example of the reciprocity theorem given by Rayleigh, and the most relevant for the discussion of the calibration of microphones, is the following:

> Let A and B be two parts of a uniform or variable stretched string. If a periodic transverse force acts at A, the same vibration will be produced at B as would have ensued at A had the force acted at B.

This technique has been central to the developement of acoustical science [Ref. 24]. As previously pointed out in Chapter I(A) the work by Maclean and Cook [Ref. 1] [Ref. 2] has been instrumental in the determination of absolute sensitivities of electroacoustic transducers.

Until fairly recently, the vast majority of the applications of the reciprocity method have been restricted to two standard geometries [Ref. 25] : The far field of a spherically radiating point source, and a pressure coupler whose

dimensions are small compared to the wavelength of the sound involved. In 1978 Rudnick [Ref. 4] demonstrated that the acoustical transfer impedance provided the necessary calibration constant and calculated the reciprocity relation for calibration in plane-wave and Helmholtz resonators. The validity of the expression in a plane-wave resonator has been demonstrated experimentally [Ref. 5] [Ref. 26].

Recall from chapter I(B) that thermal waves, initiated by variations in temperature and entropy, propagate within He II. This was referred to as second sound [Ref. 14].

The purpose of this section is to extend the technique, long recognized as the method of choice for absolute calibration of acoustic transducers, to reversible, linear, second sound transducers, and thereby provide a method for precise, absolute measurement of temperature oscillations in superfluid helium without use of a primary standard.

B. ACOUSTIC TRANSFER IMPEDANCE

Recall from chapter I(A.2), equation 1.35, that

$$Z = S/M = \text{constant}.$$

Also, the absolute sensitivity can be found by equation 1.36

$$Mo = [V(2)/(I(1)\ Z)]^{1/2}$$

It then follows that

$$S = [V(2)\ Z/I(1)]^{1/2} \qquad \text{(eqn 2.1)}$$

In chapter I(A.2) it was stated by equation 1.35 that Z represents the acoustical transfer impedance. Then, referring to Figure 2.1,

$$Z = P(2)/U(1) \qquad \text{(eqn 2.2)}$$

where P(2) is the pressure at the face of transducer 2 caused by the volume velocity, U(1), generated by transducer 1.

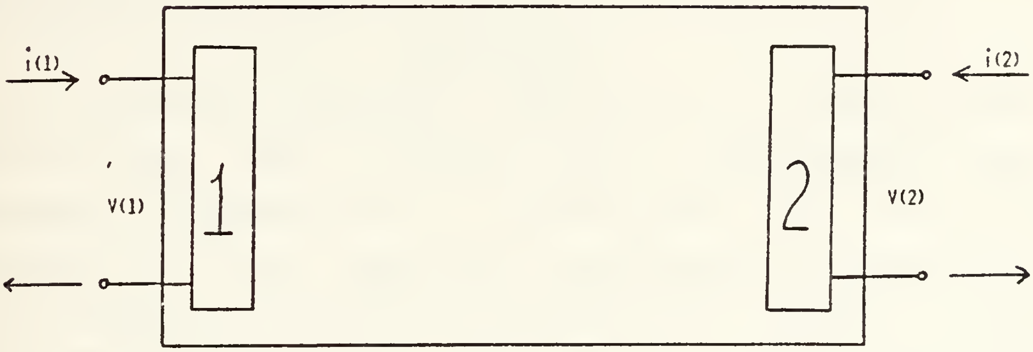

Figure 2.1 Reversible Transducers Coupled by Acoustic Medium.

The volume velocity is simply the mass flux divided by the mass density of the medium coupling the transducers, $\bar{J}/\rho$. This acoustical transfer impedance can, in principle, be calculated for any geometry. It is the ratio of the specific acoustic impedance of the medium, ρc, to a geometrical factor with the units of area. Here, c is the thermodynamic speed of sound in the medium.

For a spherically radiating source in free space [Ref. 1] this geometrical factor is $2r\lambda$, where λ is the wavelength of the sound and r is the separation of the acoustical centers of the source and receiver. For two transducers enclosed in a rigid walled enclosure [Ref. 4], all dimensions of which are much smaller than λ, the geometrical factor is $2\pi V/\lambda$, where V is the enclosure volume. For plane wave propagation in the rigid walled tube

[Ref. 27] of cross-sectional area A, the factor is simply A. Under resonant conditions, the geometrical factor will include the resonant quality factor, Q, and the mode number, n, if there is a spectrum of resonances. For a Helmholtz resonator [Ref. 4] the equivalent area is $[4\pi V/Q\lambda]$; for a plane-wave tube [Ref. 5] of cross-sectional area "A" the geometrical factor is

$$n\pi A/2Q(n).$$

We now know from the calibration procedure given in chapter I(E) that "round robin" measurements can be obtained to determine the sensitivity (M) and source strength (S) of the reversible transducers of Figure 1.9.

It should be noted that equations 1.52 and 1.66 make clear the symmetry which exists between pressure and density for first sound and temperature and entropy for second sound. It is this symmetry which will be exploited in the following section to create the expression which will permit reciprocity calibration of second sound transducers.

C. SECOND SOUND ACOUSTICAL TRANSFER IMPEDANCE

In the previous section (B) of this chapter, it was shown that the acoustical transfer impedance was required to be constant for reciprocity calibrations in classical fluids, and that quantity was the ratio of the pressure to the mass flux. To incorporate different geometries, this constant was written as a specific acoustic impedance divided by a geometric factor with the units of area. To write the expression necessary to perform the same type of absolute calibration of a reversible second sound transducer, one need only write the analogous expressions for sensitivity, M(2), source strength, S(2), and the transfer impedance, Z(2), appropriate to second sound.

As second sound is a temperature-entropy disturbance, the logical definitions for sensitivity and source strength are

$M(2)$ = xducer open ckt volts/ δT at surface
$S(2)$ = δT at mic location / driver current

or their conjugate short circuit current sensitivity and voltage source strength. If heat flux rather than entropy flux is more practical, then $S(2)$ can simply be multiplied by the ambient temperature, $T(o)$.

As before, the Reciprocity Theorem requires that if the transducer is reversible and linear,

$$S(2)/M(2) = Z(2) = T(2)/\rho S\ V\ (1) \qquad \text{(eqn 2.3)}$$

where $T(2)$ is the amplitude of temperature oscilations at the receiver created by an entropy flux $(\rho S\ V_n(1))$, generated by the transmitter.

The transfer impedance can be evaluated by expressing both the temperature oscillations and the normal fluid velocity in terms of the superfluid velocity. The necessary relations for second sound are given by Landau [Ref. 14]

$$T(2) = -U(II)\ V_s/S$$
$$\bar{V}_n = -(\rho_s/\rho_n)\{1-(\beta\rho/\rho_n S)(U(I)^2U(II)^2/(U(I)^2-C(II)^2\}\ \bar{V}_s$$
$$\bar{V}_n = -(\rho_s/\rho_n)[1-\alpha]\ \bar{V}_s$$

where α represents the second term inside the brackets, Cp is the specific heat at constant pressure and β is the isobaric coefficient of thermal expansion. Substituting equation 2.3 yields

$$Z(2) = T(o)/[A\rho U(II)Cp(1-\alpha)]\ . \qquad \text{(eqn 2.4)}$$

For all temperatures between 1.0 °K and 2.17 °K, α is less than one percent. It is worth pointing out that this

result differs from that of other authors due to the choice of entropy flux as the conjugate to temperature. Atkins [Ref. 28] derives an equivalent result which differs by a factor of $T(o)$ in the limit that $\beta = 0$ since he defines the characteristic impedance as the ratio of temperature to heat flux. Pellam [Ref. 29] chooses the less practical but equivalent definition of impedance as the ratio of "osmotic pressure" to counterflow velocity and again treats $\beta = 0$.

Using equation 2.4, we can now write the absolute sensitivity of a reversible and linear second sound transducer as

$$M(2) = M' \, [\, V(2)/(A\, I(1))\,]^{1/2}$$

$$M' = [\, U(II)\, Cp(1-\alpha)/T(o)\,]^{1/2}$$

where 'A' is again some effective area which depends upon the acoustic geometry which couples the source and receiver as discussed in section (B) of this chapter. M' is the temperature dependent calibration constant.

It is worth pointing out that a previous attempt to derive this result [Ref. 30] has been shown to be incorrect [Ref. 31] because the resulting expression contained a transducer dependent quantity.

D. SECOND SOUND RECIPROCITY CALIBRATION CONSTANT

The calibration constant, M', has been evaluated using the UCLA second sound speed data [Ref. 32] and the derived hydrodynamics [Ref. 21] in Table II and Figure 2.2 for the saturated vapor pressure. The behavior of this constant in the region from 1.2 °K to 1.9°K has the experimentally convenient feature of being linear in temperature. The points in Figure 2.2 are the data of Table II. The straight line is a least square fit to the points between the temperatures 1.2 °K and 1.9 °K, given by

$$M'(T) = 2.176\, T - 1.775$$

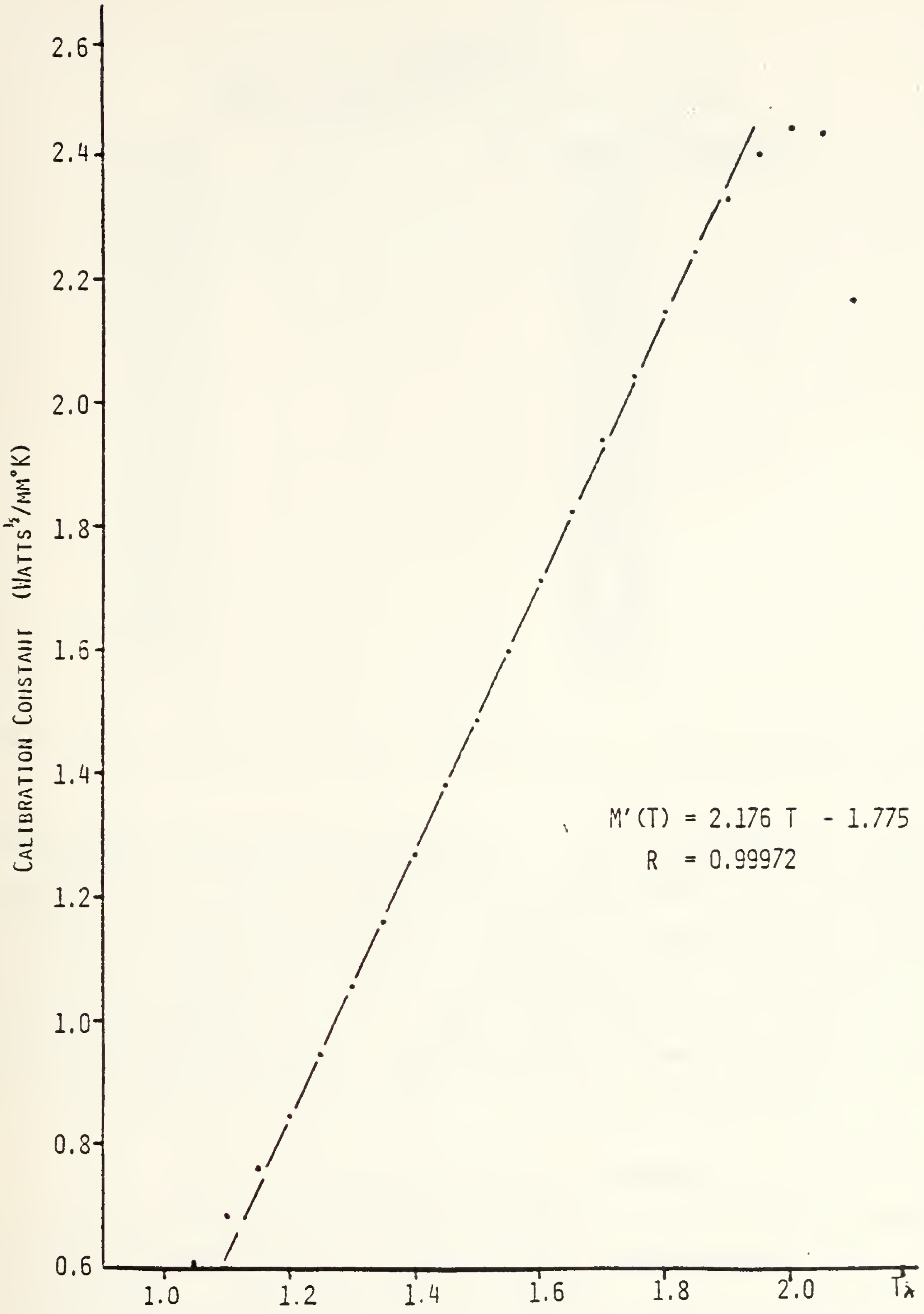

Figure 2.2 Second Sound Reciprocity Constant.

TABLE II

Second Sound Reciprocity Constant

T (°K)	M' [watts$^{1/2}$/mm-°K]
1.00	5.31
1.05	6.05
1.10	6.85
1.15	7.60
1.20	8.45
1.25	9.42
1.30	10.44
1.35	11.51
1.40	12.69
1.45	13.73
1.50	14.86
1.55	16.00
1.60	17.14
1.65	18.26
1.70	19.39
1.75	20.46
1.80	21.49
1.85	22.45
1.90	23.30
1.95	24.02
2.00	24.44
2.05	24.74
2.10	24.38
2.15	21.66

with units of [watts$^{1/2}$/(mm-°K)]. The correlation coefficient of the fit is 0.9997 which corresponds to a standard deviation of less than 0.7% over the 15 temperature points. The linear behavior can be understood as a consequence of the thermodynamics of an ideal Bose-Einstein gas and the "Tisza approximation". Neglecting the small correction due to the expression coefficient, $Z(2)^2$ can be written

$$Z(2)^2 = \rho^2(\rho_s/\rho)(\rho S/\rho_n)S \quad [\partial S/\partial T] .$$

For the ideal Bose-Einstein gas $S = 1.284(T/Tc)^{2/3}$ where Tc is the condensation (transition) temperature [Ref. 33], so $S(\partial S/\partial T)$ is proportional to T^2. If the entropy is carried only by the normal component and the entropy of the

normal component is assumed constant, then $S = \rho_n S_n$ and $(S \rho / \rho_n)$ is temperature independent. This is known as the Tisza approximation [Ref. 34], which is found to be correct above 1.2 °K. Although ρ_s / ρ is a strong function of temperature near the lambda-point, the square root of its value rapidly approaches one below 1.8 °K. The total density is very nearly temperature independent.

III. APPARATUS

A. CRYOSTAT

Figure 3.1 is a diagram of the dewar and associated support piping systems. The piping and tubing systems are primarily copper with silver brazed joints, although rubber vacuum tubing is used in small sections.

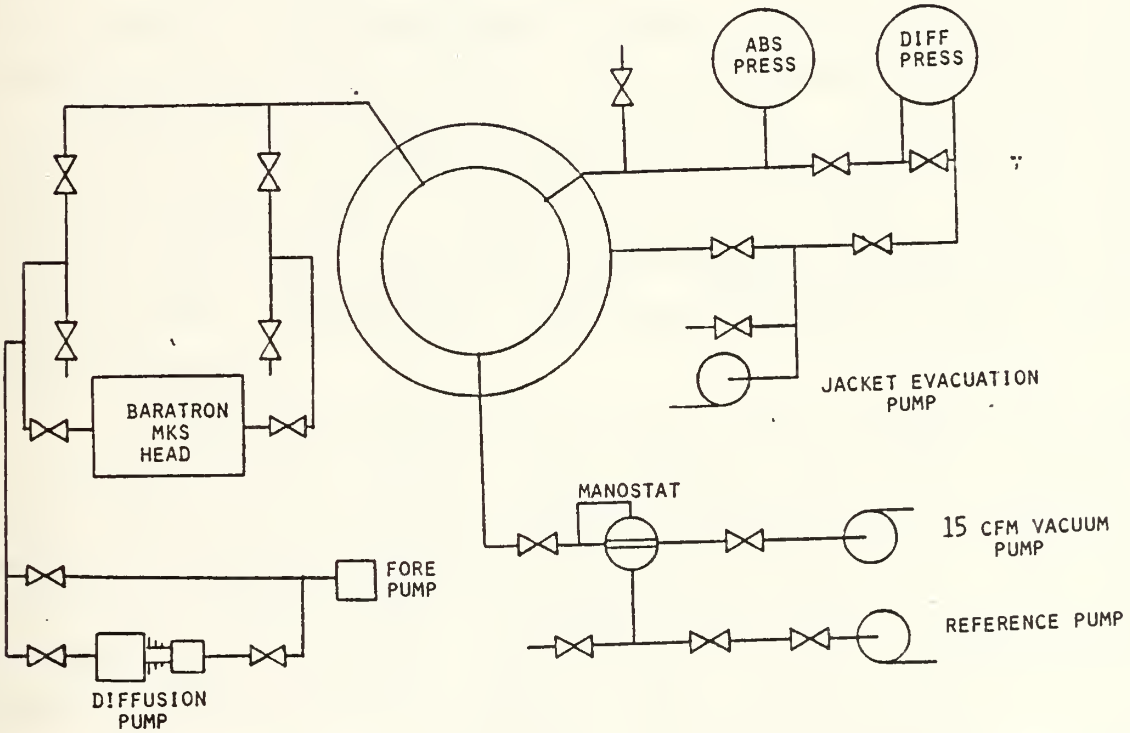

Figure 3.1 Dewar Support Piping Systems.

1. The Probe

The probe pictured in Figure 3.2 provides mechanical support for the experiment inside the dewar, electrical connections between the transducers and the room temperature electronics and a means of introducing liquid helium into the dewar.

The liquid helium fill tube is made in two sections. The first section is the portion that resides outside the dewar area in atmospheric conditions (Helium Recieving Tube). This section is an 8 inch (20.32 cm) long, 15 mil (0.038cm) wall and 0.662 inch (1.68 cm) outside diameter stainless steel tube. The second section is that portion inside the dewar. This section is 58 3/8 inches (148.27 cm) long, 9.8 mil (0.025 cm) wall and 1/2 inch (1.27 cm) out side diameter stainless steel tubing. The two sections are joined inside the top-plate. The difference in tubing size was necessitated in that the atmospheric section must be large enough and strong enough to accept and support the helium transfer tube, while the dewar portion of the fill tube has thin wall size which was choosen to reduce the heat leak (thermal conduction) from the top-plate which is at room temperature.

The dewar portion of the fill tube, which also acted as the main support tube, has 1/8 inch (0.32 cm) diameter holes placed approximately every 8 inches (20 cm) along its length to prevent Taconis oscillations [Ref. 35]. The fill tube has 4 heat shield assemblies that are attached to the central tube to reduce the heating of the helium due to Stefan-boltzman, σT^4, radiation from the top-plate which is at room temperature. At the bottom of the fill tube is a Bakelite plate which supports the experiment.

The top-plate is a 4 11/16 inch (11.9 cm) diameter, 1/8 inch (0.32 cm) thick brass plate.

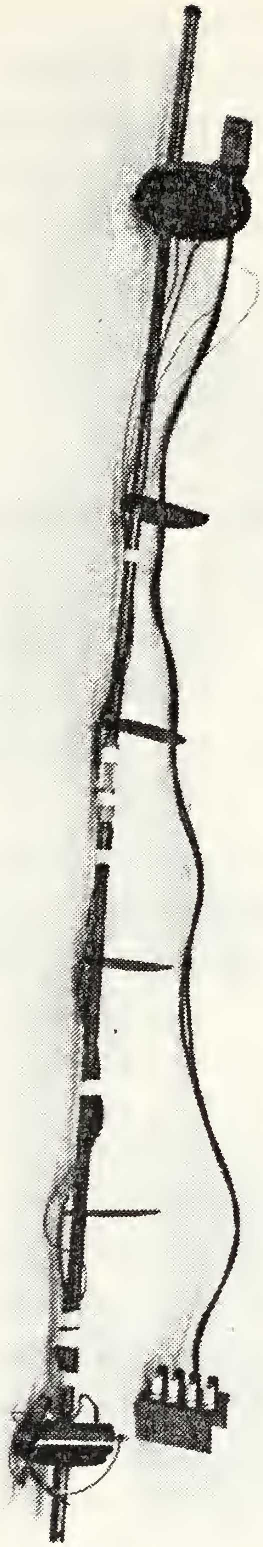

Figure 3.2 The Probe.

The top-plate provides support as well as providing the seal between the low pressure low temperature experimental area inside the dewar and the atmosheric conditions outside the dewar. The top-plate has the following penetrations:

(1) fill tube (helium recieving tube)

(2) hermetically sealed, dual BNC recepticle box which allows two way electronic communication between room temperature electronics and the two capacitive end plates of the resonator

(3) a BNC connection which provides a signal path to the resonator resistor

(4) a 1 inch (2.54 cm) high 9/16 inch (0.46 cm) outside diameter brass tube which contains 4 twisted pairs of wire which is passed through a hermetic seal in the tube.

The 4 twisted pairs are used for a 4 terminal connection to a calibrated resistor used for temperature monitoring during cooldown and the second sound drive heater in the experimental cell (resonator).

The heat conducted to the helium by the thin walled stainless steel tubing supporting the experiment was calculated by using the following information from Goodall [Ref. 36]. For a 10 cm length of stainless steel tubing of 1/2 inch (1.27 cm) O.D. with a wall thickness of 6 mils (0.002 cm), running from 300 °K to 4 °K, will conduct 184 mWatts of heat. As the distance from the helium surface to the top-plate was typically 110 cm, the central tube contributed a heat load of 27.9 mWatts.

The heat calculated for the 4 twisted pairs (8 wires total) of #32 gauge (Brown and Sharp) copper wire (164.5 cm/wire) was performed using the following data from Reference 40. A 10 cm piece of #34 British wire gauge with

a crossectional area of 0.429×10^{-3} cm^2, with one end at 300 °K and the other end at 4 °K, provides a heat leak of 65.2 mWatts. Multiplying by a crossectional area ratio between #34 gauge and #32 gauge wire and the number of wires and then dividing by the length ratio results in the twisted pair heat load of 23.7 mWatts.

The two coax cables, with crossectional area of 0.0065 cm^2 and length of 110.9 cm were modeled as thin walled stainless steel tubes since no heat load information for coax cabling was readily available and the contribution of the teflon insulation is insignificant. Again following Goodall [Ref. 36] the following calculation was made. A 10 cm long piece of 1/2 inch (1.27 cm) O.D. stainless steel tubing with a crossectional area of .0098 cm^2 running from 300 °K to 4 °K conducts 30 mWatts. Scaling the 30 mWatts by the crossectional area ratio divided by the length ratio times the number of coax cables yielded a heat leak of 3.6 mWatts.

The calculation of heat input (worst case) due to the contributions of the individual elements discussed above is summarized as follows:

THIN WALL TUBE	27.9 mWatts
TWISTED PAIRS	23.7 mWatts
COAX CABLE	3.6 mWatts
TOTAL	55.2 mWatts

A run was conducted on 27 October 1982 to determine an actual system heat leak. A plot of Helium Height (cm) verses Time (minutes) over a period of 400 minutes resulted in a slope of -11.6×10^{-3} cm/min with a correlation coefficient of 0.997. This slope was converted into a boil-off rate and multiplied by the latent heat of vaporization of

helium at 1.65 °K (L=3.27 Joules/cc) [Ref. 37] to yield experimentally calculated heat leak. For this case the leak is 51 mWatts, which is in excellent agreement with the previous analysis. This heat leak rate permitted 82.2 hours of run time and a minimum temperature of 1.4 °K using the 15 CFM pump assuming no energy input to the system. The fact that our worse case calculations exceeded the observed depletion rate, hence power input, indicates no significant unknown heat leaks exist within the dewar.

2. Dewar System

All experiments were performed in a glass double dewar system. The inner dewar is 4 inches (10.16 cm) inside diameter. The temperature of the helium bath is reduced by pumping away its vapor with a Kinney vacuum pump, Model KC-15. The connection between the pump and the dewar is by means of a 2 1/4 inch (5.7 cm) outside diameter pipe which tapers to a 1 1/2 inch (3.8 cm) outside diameter pipe. The 1 1/2 inch O.D. line has an isolation valve which isolates the pump from the dewar.

The helium bath temperature is determined by measuring the vapor pressure of the helium and converting it to temperature by Cubic Spline interpolation [Ref. 38] using tables based on the 1958 He temperature scale [Ref. 39]. The pressure is measured by a MKS Baratron, head type 370 H, with a 0-1000 mmHg range. An analog voltage output which is proportional to the pressure is sent to the computer controlled data aquisition system. The reference side of the differential head is backed by a diffusion pump so the pressure reading can be regarded as absolute.

A vacuum drop test of the dewar, covering a three day period resulted in the following:

(1) first 24 hour period leak rate was 0.154 mmHg/hr

(2) three day period leak rate was 0.120 mmHg/hr .

Since the volume of the inner dewar space is 12.15 liters this corresponds to a leak rate of 0.0048 standard cc/sec. This rate is sufficiently small to allow operation of the experiment for periods in excess of 50 hours. No icing of the inner dewar space was visible at any time.

3. Temperature Control (Pressure Control)

Temperature was controlled by controlling dewar pressure and thereby controlling the vapor pressure of the helium contained within. The pressure is controlled by the use of a manostat [Ref. 35]. The manostat is located in the dewar vacuum system between the 1 1/2 inch (3.8 cm) O.D. isolation valve and the dewar itself (see Fig 3.1).

The manostat shown in figure 3.3 is a 6 inch (15.24 cm) inside diameter 3 inch (7.62 cm) deep cylindrical aluminum vessel. The top is constructed out of 1/4 inch (0.635 cm) thick clear polyethylene. The manostat has four piping penetrations. Two are 1 1/8 inch (2.86 cm) O.D. which are used to place the manostat in the vacuum system between the vacuum isolation valve and the dewar. The penetrations protrude 1 1/2 inches (3.8 cm) into the vessel radially from opposite directions leaving a 3 inch (7.62 cm) gap between them. A condom (Shiek Reservoir End Sensi-Creme Lubricated) with the end cut off was placed over the ends of the two protrusions and is held on each end by an O-ring. This flexible membrane acts as an extremely sensitive control valve. The other two penetrations are 3/8 inch (0.95 cm) outside diameter. One connects to a reference flask and the other connects through an isolation valve to the dewar side vacuum line to sense dewar pressure.

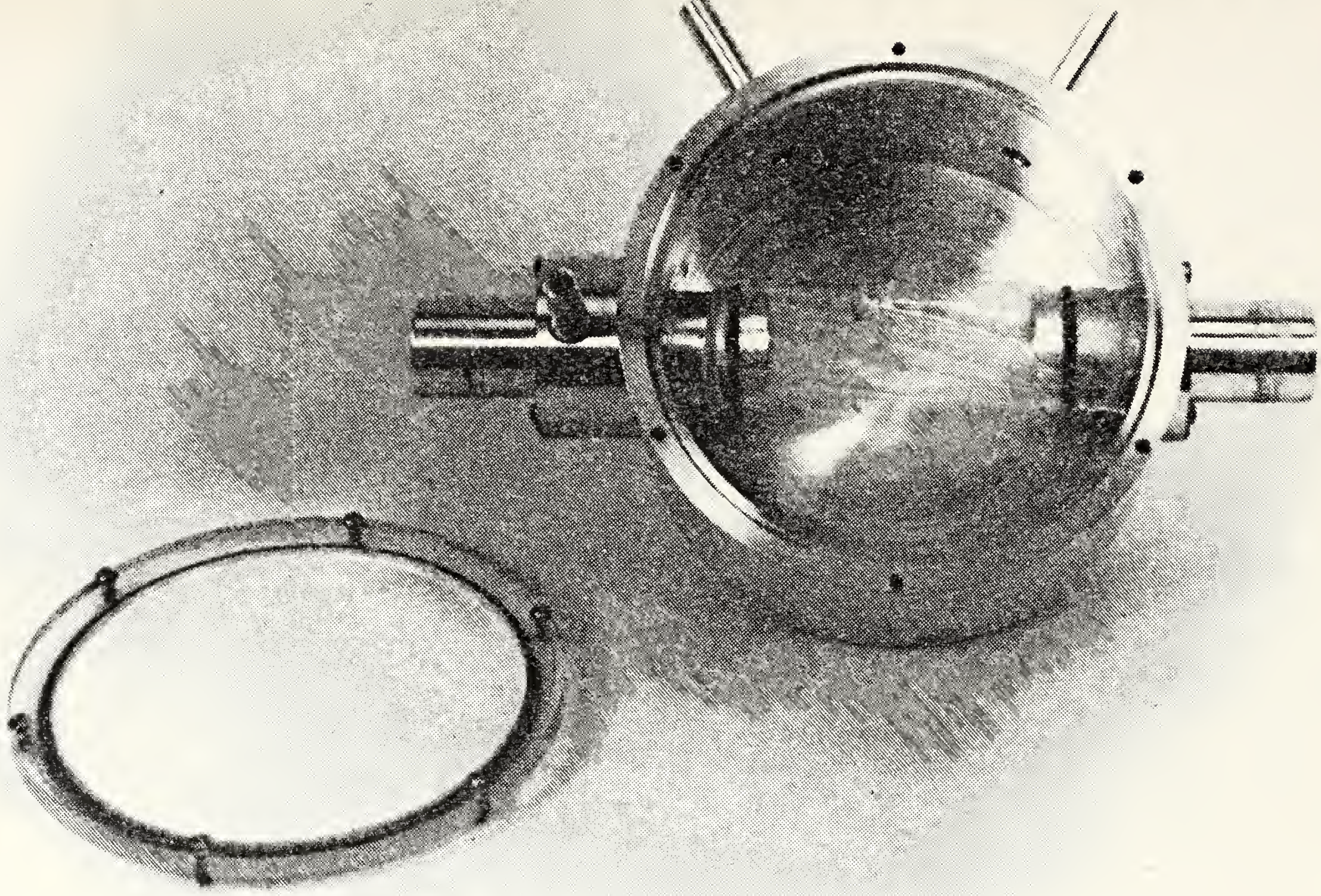

Figure 3.3 The Manostat.

With the isolation valve in the open position, the pressure inside and outside the membrane are equal, allowing the membrane to remain in an uncollapsed state. This permits the vacuum pump to continue to evacuate the dewar. When the desired pressure is reached (2.5-30.0 mmHg) the isolation valve is shut. The pressure in the dewar at the time the isolation valve is shut is the pressure felt and maintained on the outside of the membrane. The inside of the membrane is sensing present dewar pressure. If the dewar pressure drops below the desired pressure, the pressure inside the membrane drops below that maintained on the outside of the membrane causing it to collapse and thereby isolating the vacuum pump from the dewar. As the liquid helium evaporates and vapor pressure increase the pressure inside the membrane also increases. When the dewar pressure exceeds the pressure maintained on the outside of the membrane the condom begins to expand and once again opens a path between the vacumn pump and the dewar to allow the pressure to be decreased and thereby decrease the system temperature.

This manostat was found to be quite reliable and was able to maintain a constant pressure to within 0.025 mmHg over a one hour period. This relates to an approximate 0.004 degree Kelvin temperature change over the same time period in our temperature range of concern.

The choice of condom was found to be suprisingly important. Several different types and brands were used but the Shiek Sensi-Creme Lubricated was found to be most pressure sensitive and capable membrane for maintaining a desired pressure.

B. TRANSDUCTION

1. The Resonator

A cylindrical plane-wave resonator geometry was determined to be the best choice for testing second sound reciprocity calibration. The slow speed of second sound U(II) is less than 20 m/s and the consequent shortness of wavelengths limits the frequency range of a coupler to inconvenient dimensions. While restricting our experiment to a limited number of operating frequencies, at a given temperature, the plane-wave resonator guarantees a well defined geometry, plane wavefronts below cut-off for higher order modes [Ref. 40], and simplicity of design.

A schematic diagram of our resonator, previously illustrated in chapter I(E), is repeated here in Figure 3.4. A picture of the actual experimental resonator is shown in Figure 3.5.

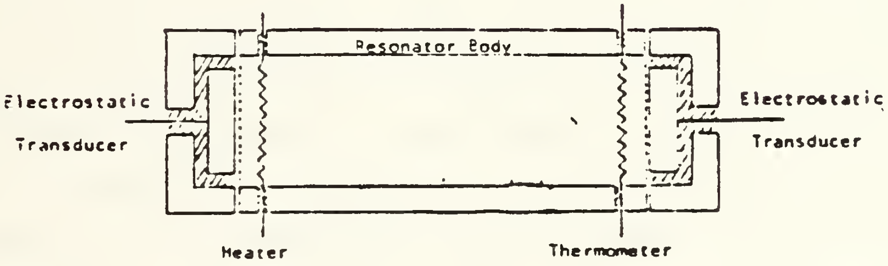

Figure 3.4 Schematic of Experimental Resonator.

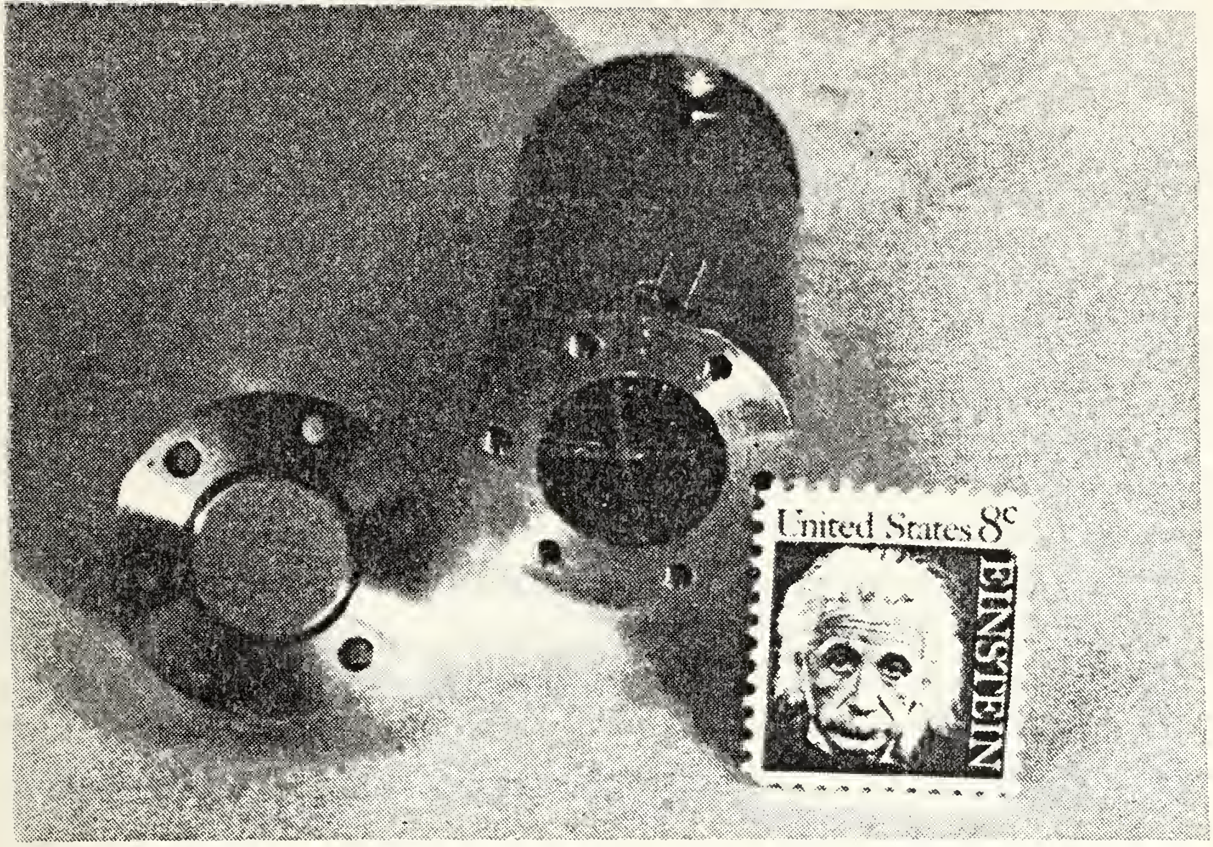

Figure 3.5 Experimental Resonator.

The resonator is made of brass (5.0 cm in length and 2.54 cm OD) and has been longitudinally bored (1.43 cm ID). The two cylindrical endcaps contain epoxy (slanted lines) insulated metal "buttons". When combined with transduction elements which incorporate electret technology [Ref. 41], they form two reversible, mechanical and electrostatic second sound transducers. Micro-dot connectors on each end provide an electrical interface to make positive electrical connection to the grounded endcaps and the electrically "hot" buttons. The button faces have been lightly sandblasted to improve their sensitivity when they are used as the hot electrode in an electret microphone consisting of the button as a backplate and the electret as the pressure sensitive diaphragm. The endcaps contain a very narrow and shallow trough on their face which mates with the resonator body, thus providing a free flooding port for liquid helium to completely fill the experimental chamber.

The heater has been constructed from insulated #41 manganin wire. The wire (0.0057 cm diameter) was found to offer 51.66 Ω/ft using an HP-3456A multimeter with null. The wire was fashicned into an acoustically transparent "web". It is used to generate thermal waves (second sound). A picture of the heater is provided in Figure 3.5.

The thermometer has been fabricated from an Allen-Bradley carbon composition resistor (1/10 watt) which has been sanded to form a thin slab. This type resistor was chosen due to its high differential resistivity [d(ln R)/dT] in the 1-2 °K range. It can be calibrated against the vapor pressure curve [Ref. 39] and then used as a detector (microphone) of second sound. In a later section (Transducers: Thermometers) we discuss our attempt to improve on the Allen-Bradley thermcmeter and our motivation for improvement. A picture of our resistive thermometer is provided in Figure 3.6.

2. Transducers

a. Electret-type

In our resonator the pressure disturbances, as well as the counterflow of the super and normal components, are detected using the electret microphone [Ref. 42] which consists of an aluminized sheet of 1/2 mil (12.7 μm) thick FEP teflcn laid on the endcaps with the aluminized surface away from the buttcn. A large quasi-permanent charge density, σ, of the crder of 10^{-7} coulomb/cm^2 [Ref. 43] is deposited in the aluminized teflon by placing it in an electric field. The membrane is pclarized by placing it, aluminized side up, on a sheet of ordinary window glass and applying 12-18 KVDC across the aluminized surface and a conducting plate under the glass. The electric field is maintained for approximately 1-3 hours. Then the electret

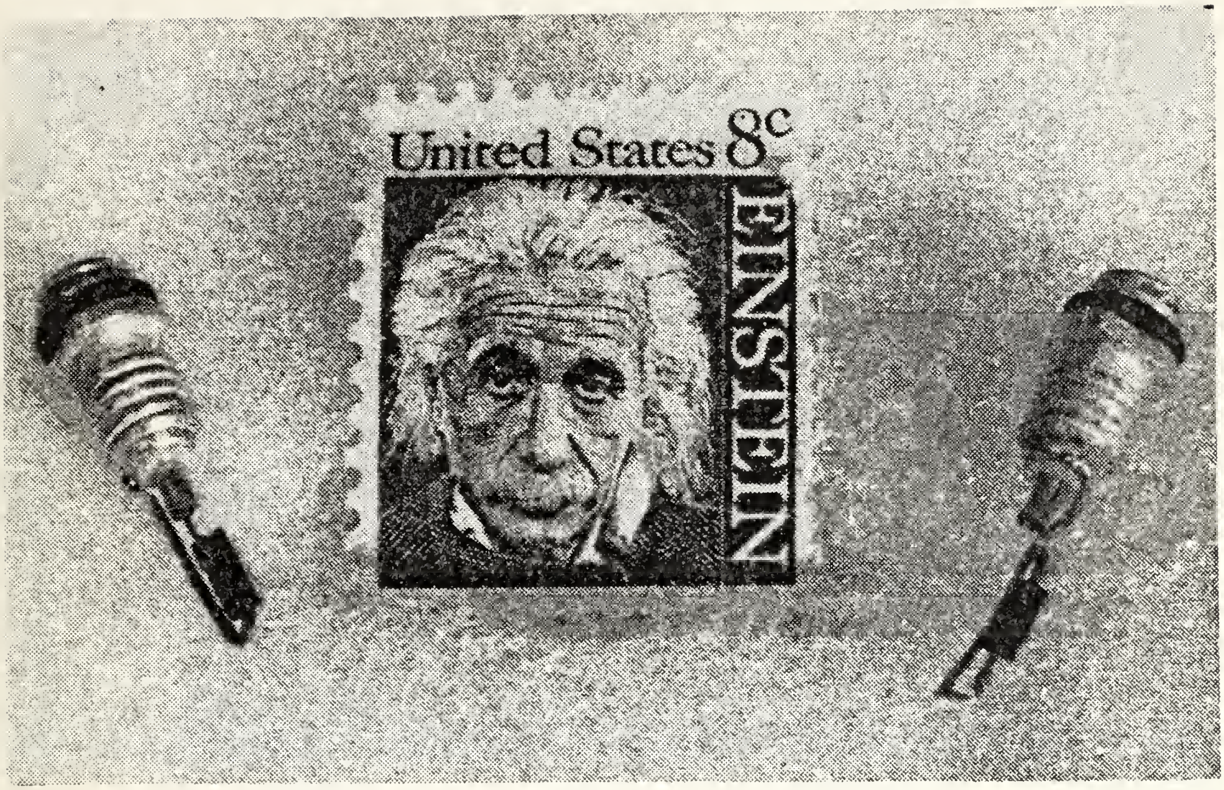

Figure 3.6 Resistive Thermometer.

is removed from the glass and placed over the sandblasted electrode (button) to which it adheres due to electrostatic forces. Holes for the fastening screws, which tightly sandwich the endcap to the resonator body, and random slits, for passage of He II, are cut in the electret with a scalpel. This can be seen in the following figures which show pictures that were taken of our slit-electrets using an electron microscope. Figure 3.7 gives an overview of a typical electret showing the random number of arbitrarily placed slits. In Figure 3.8 it is possible to see the detail of the slits, especially noticeable is the jaggedness of the slits and the areas of apparent arcing that has occurred during testing. From such slit-electret resonators we were still able to consistantly obtain spectral diagrams which clearly showed multiple resonances, as illustrated in figure 3.9.

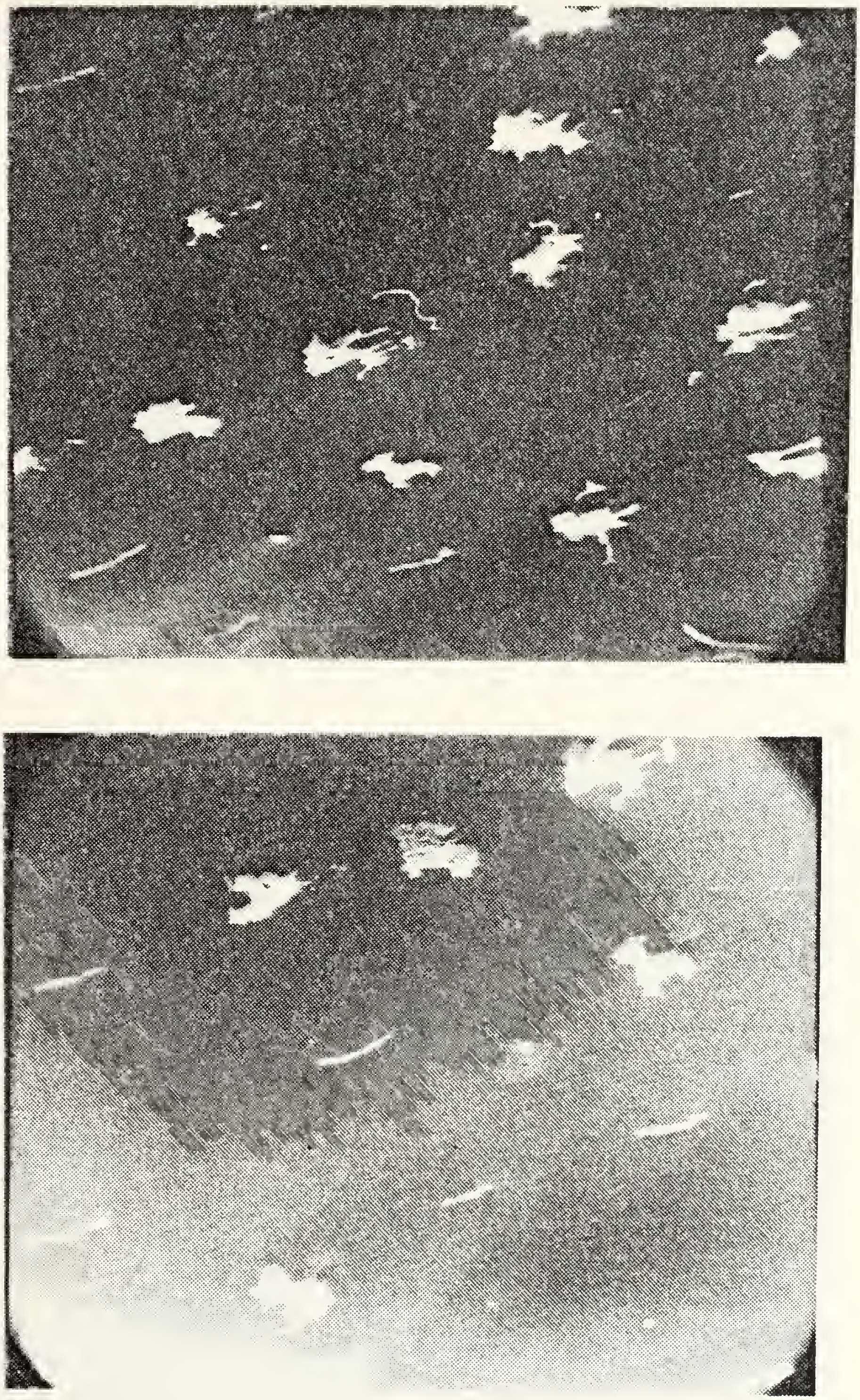

Figure 3.7 Overall View of Electrets (x20).

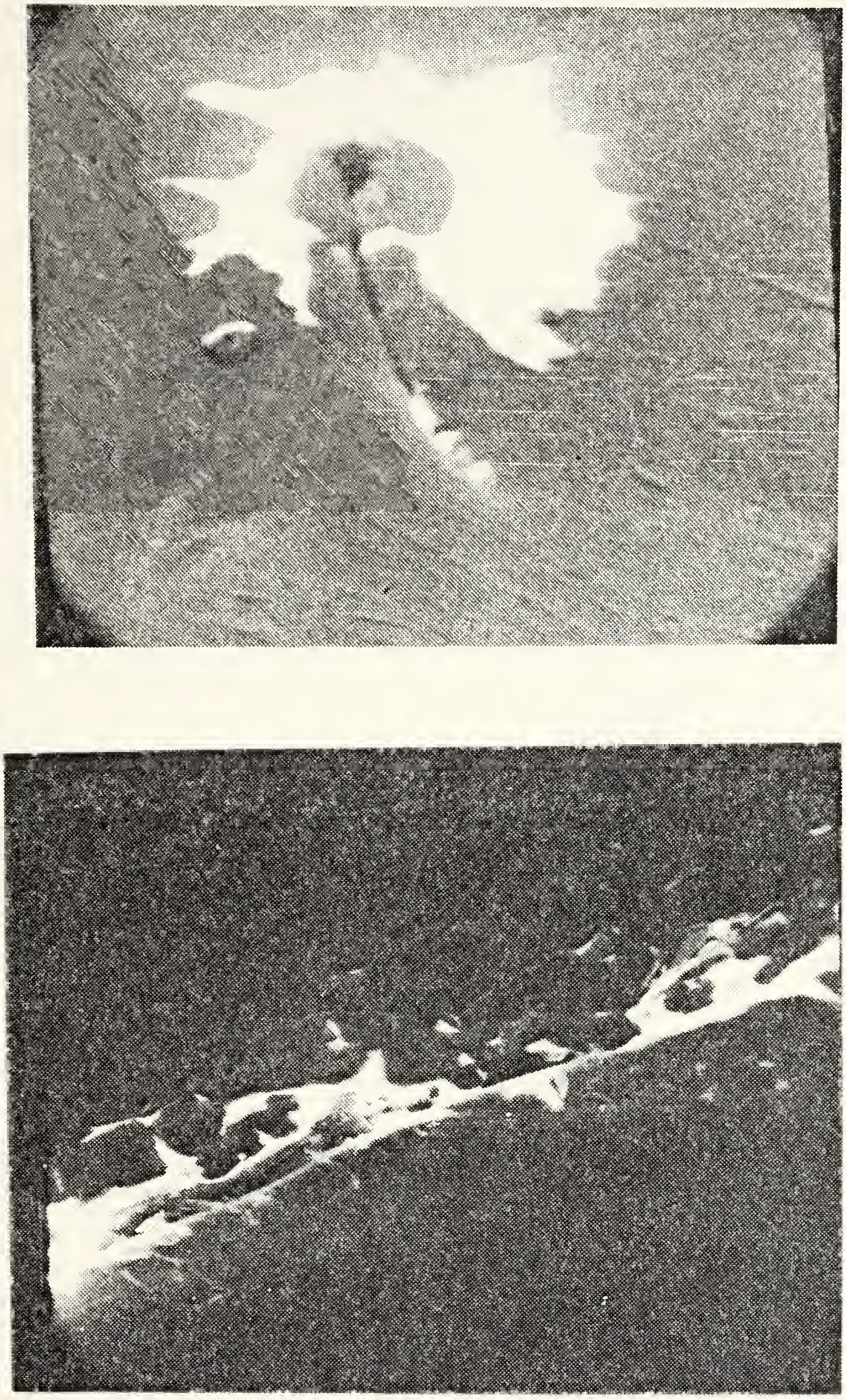

Figure 3.8 Close-up On Electret (x120) and Slit (x600).

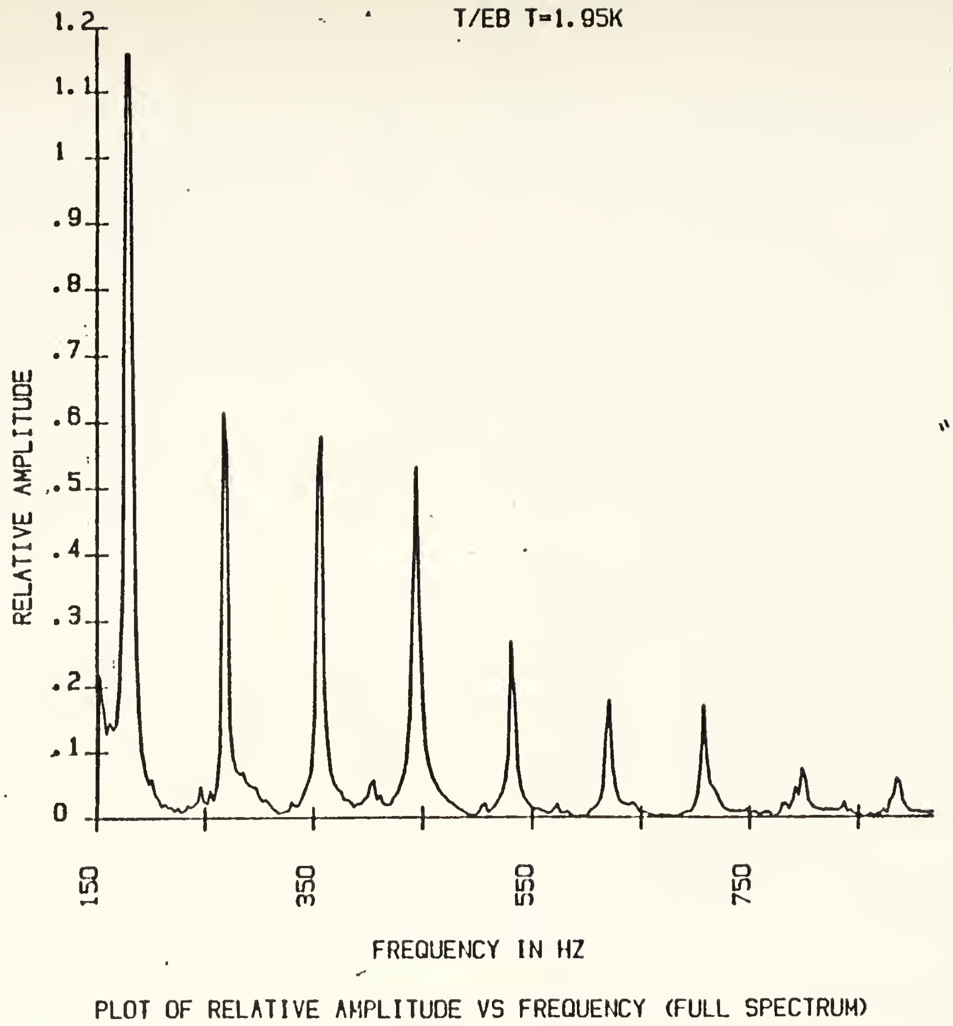

Figure 3.9 Typical Display of Multiple Resonant Modes.

When an oscillating voltage of frequency ω is applied between the electret and the button, the driver acts like an electrostatic speaker coupled directly into the resonator. Since the electret has a stored charge which has been found to have an equivalent bias voltage ranging from 150-210 volts [Ref. 44] the sound generated by the driver will also be at ω without an external biasing voltage.

Within the resonator, pressure and super/normal fluid component counterflow are detected using the electret device as a microphone. Therefore, a voltage is generated between ground (resonator body) and the button whenever there is an oscillation of the membrane. This causes the membrane to deviate from its equilibrium position and thereby changes the capacitance between the electrode and the aluminized surface. The charge on the electret is fixed and $Q = CV$, where $Q = \sigma A$ and A is the surface area of the button (almost 0.25 cm^2), C and V are the capacitance and equivalent voltage across the aluminized surface and the backplate. When the membrane is displaced by a small amount we can let

$$C = C(o) + \delta C(t) \qquad \text{(eqn 3.1)}$$

and

$$V = V(o) + \delta V(t) \qquad \text{(eqn 3.2)}$$

and

$$[\delta C(t)/C(o)] = [-\delta V(t)/V(o)] \qquad \text{(eqn 3.3)}$$

where $V(t)$ is the time varying voltage generated by the membrane displacement and $V(o)$ is the equivalent bias voltage across the transducer due to the stored charge density in the electret. As stated before, this equivalent bias voltage is approximately 150-210 volts for our typical electrets. This value was determined utilizing the circuit of figure 3.10.

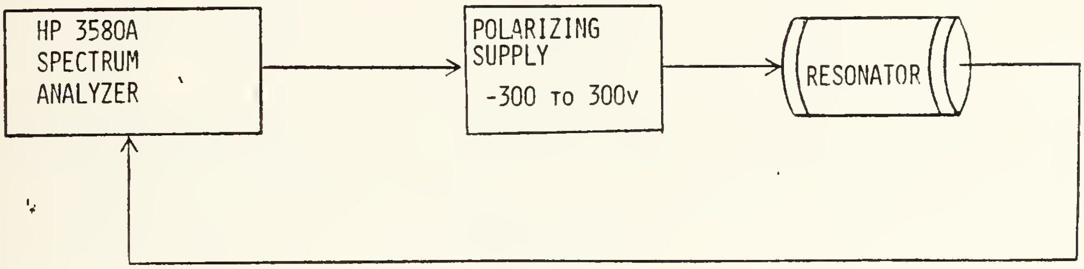

Figure 3.10 Determination of Electret Equivalent Bias Voltage.

While driving the electret of side A with the d.c.-bias voltage, the relative microphone (side B) response is monitored. After plotting the relative response as a function of the increased bias voltage, a linear extrapolation of the relative response to a "zero volt" condition yields, experimentally, the equivalent bias voltage, $V(o)$, of the electret microphone (side B). Figure 3.11 shows some typical data taken at 293 °K. It is worth pointing out that this technique of measuring bias voltage worked equally well in helium or at room temperature.

During the experiment it was necessary to determine, to as high a degree of accuracy as possible, the capacitance of these electrostatic transducers. In addition

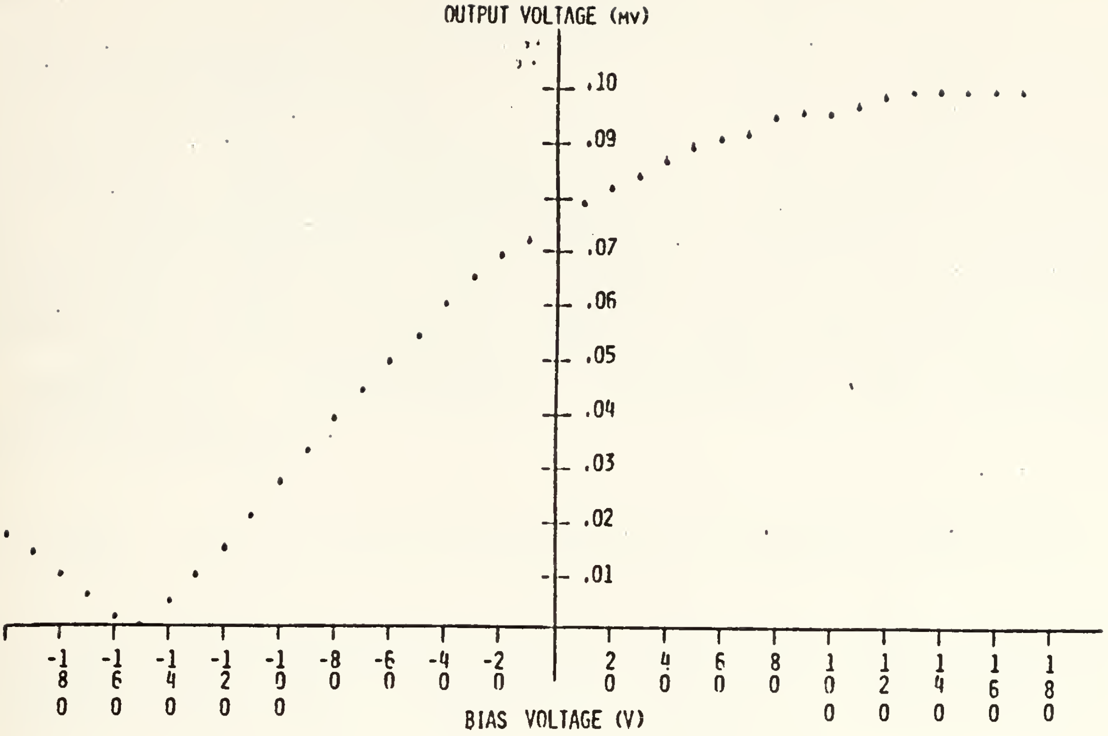

Figure 3.11 Back-bias Volts vs. Received Acoustic Signal.

to correcting for the inherent capacitances of peripheral equipment and leads, covered in a later section, it was also necessary to account for the dead capacitance of the endcap-button ensemble. This dead capacitance is the transducer's capacitance without the electret in place. For our electrets the average value of dead capacitance was found to be 12.7 ± 1.4 pf.

The process of driving an electret source (A) and picking up on an electret microphone (B) is denoted EA/EB. This process was used in the experiment to determine the product of sensitivities [M(A) M(B)] by the Reciprocity Theorem

$$M(A)\ M(B) = [\,V(m)/(i(s)\ Z)\,]$$

where

$$i(s) = V(s)(2\pi fC), \qquad \text{(eqn 3.4)}$$

"f" being the resonant frequency and C the driver capacitance. The parameter Z, as previously mentioned, depends on the measured values of Q and A [area] as well as some thermodynamic quantities [specific heat, second sound speed, He II density and temperature]. Therefore, the resulting equation appears as

$$M(A)M(B) = [d^2\pi U(II)C_p\rho/16][V(m)n/(V(s)QfCT)] \qquad \text{(eqn 3.5)}$$

where d is the experimental chamber diameter, and the other parameters have been previously defined. The units of equation 3.5 are (volts/ ^{0}K)^2, as expected.

In order to obtain the absolute sensitivity of our individual electret transducers we need to conclude the reciprocity procedure. We will choose to drive thermally (heater) and pick up on electret. This is denoted T/EA or T/EB, depending on which electreted side is to play the role of the microphone. The results of this approach will be the _ratio_ of the sensitivities.

We now take great care to drive the heater with a voltage V(i) that is necessary to produce an equivalent response from side B as obtained when electreted side A was being driven[2] (the choice of A or B is arbitrary).

After the input and output voltages are recorded, the output response of side A is recorded, while the heater drive remains the same.

---

[2] We have found that this is an unnecessary restriction since for typical drive voltages of interest to us, and within the power limitations of the heater, the transducers respond linearly.

This then gives us

$$M(A)/M(B) = [T/EA]/[T/EB] \tag{eqn 3.6}$$

where for the values obtained from T/EA we get

$$T/EA = V(o)/V(i)^2. \tag{eqn 3.7}$$

For the different set of values obtained for T/EB we get

$$T/EB = V(o)/V(i)^2. \tag{eqn 3.8}$$

Therefore by equation 3.6,

$$M(A) = M(B)\,[T/EA]/[T/EB]\ . \tag{eqn 3.9}$$

After substituting equation 3.9 into equation 3.5 we find that

$$M(A) = (\text{constant})[\text{available data}]^{1/2} \tag{eqn 3.10}$$

and now M(B) can be determined from equation 3.9. As will be pointed out later, there is sufficient data to determine M(B) using equation 3.10 and M(A) can be measured by comparison (equation 3.6). This provided a self-consistancy check of our procedure.

b. Thermophone

The heater element is made from a 1.2 ft length of insulated manganin wire which has been folded in half and twisted. As previously stated this wire offers $51.6\,\Omega$/ft. The twisted wire was spirally-threaded through holes located in a mylar crossbar arrangement whose arms are only slightly shorter than the diameter of the resonator chamber. This is

to ensure a snug fit when the spiral heater is epoxied into place just within the chamber (recessed less than 2 mm) and literally out of touch with the aluminized side of the electret transducer. Figure 3.6 shows the heater.

The heater is driven by a sinusoidally time-varying voltage at half the frequency of the desired second sound. Since the heating is proportional to the square of the applied voltage the generated second sound is at twice the frequency of the applied voltage according to Pellam [Ref. 22]. That this is true can be seen from the trigonometric identity,

$$\cos^2(\omega t) = (1/2)[1 + \cos(2\omega t)], \qquad \text{(eqn 3.11)}$$

which shows that only half of the electrical signal delivered to the heater goes into creating second sound (at 2ω) and the other half goes into d.c. heating of the fluid.

In the previous discussion on electrets we were able to use the Reciprocity Theorem to calculate the absolute sensitivities of our transducers without the use of a primary standard and with only easily obtainable parameters. But how good are these sensitivities?

In order to determine whether these values are absolutely correct we must at least compare our calibrations against some standard. The thermophone principle can be used to set an upper limit for our calibration if we make the following assuption. Although only half of the signal delivered to the heater is instrumental in generating second sound, we calculate the temperature swing that would occur if **all of this** power that is available (at 2ω) goes into the production of second sound. Pellam has shown us how to calculate the second sound amplitude; however, we know that there is always energy leakage at least along the electrical leads, and so calculations derived from this assumption are

surely upper limits for expected temperature swings necessary to produce a given output.

The derivation of the necessary equation to determine this temperature swing for the thermophone follows from previously stated relationships which will not be restated here. The electrical power that is available for the production of second sound will be equal to I^2R where I is the rms current supplied to our heater of resistance R. A reinforcement factor of $(2Q/n\pi)$, used for classical resonator systems (and used by Pellam for n=1), will be used to enhance the temperature oscillation amplitude due to resonance. If we define

$$\text{power/Area} = \rho S V_n T(o) \qquad \text{(eqn 3.12)}$$

$$V_n = -\rho_s V_s / \rho_n \qquad \text{(eqn 3.13)}$$

$$\text{Power/Area} = -\rho S T(o) \rho_s V_s / \rho_n \qquad \text{(eqn 3.14)}$$

therefore,

$$V_s = -(\text{Power}) \rho_n / (\rho_s \rho S T(o) \text{ Area}). \qquad \text{(eqn 3.15)}$$

From chapter II and according to Landau [Ref. 14],

$$\delta T = -U(II) V_s / S \qquad \text{(eqn 3.16)}$$

$$\delta T = U(II) [(\text{Power}) \rho_n / (\text{Area } \rho_s \rho T(o) S^2)] \qquad \text{(eqn 3.17)}$$

the re-enforcement factor must also be included, therefore,

$$\delta T = [U(II)\ 2Q\ (\text{Power})\ (\rho_n/\rho_s)]/[\text{Area}\ S^2\ n\rho\pi T(o)]$$

but since the specific heat at constant pressure is

$$Cp = (\rho_s/\rho_n)\ T(o)\ S^2\ /\ U(II)^2\ , \qquad \text{(eqn 3.18)}$$

then,

$$\delta T = 8Q\ V(i)^2/[R\rho\ \pi^2\ n\ d^2\ Cp\ U(II)\ \text{sqr}(2)] \qquad \text{(eqn 3.19)}$$

where V(i) is the rms voltage into the heater of resistance R, n is the modal number, and d is the chamber diameter. Therefore, with readily available data we are able to calculate, and thereby set, an upper bound for our reciprocity calculations made earlier.

c. Thermometry

Thermometry, like the thermophone, is a principle that will be used to again test our reciprocity calibration of thermal transducers within a quantum fluid. However, this time we will use our resistance thermometer to set a lower bound for a temperature swing producing a particular output.

The second sound generation (heater) and pick up by the carbon resistance thermometer is referred to as thermal-thermal and is denoted T/T. The thermometer was fabricated from an Allen-Bradley 1/10 watt resistor. It was sanded down until approximately 1mm thick in order to minimize its thermal inertia. The thermometer has been electrically interfaced with peripheral equipment by a micro-dot connector, thus making it modular, and fully shielded.

The principle employed in the resistance thermometer, for the detection of second sound, is that the resistance (R) is a function of temperature and if a constant current, I, passes through the resistor, then the changes in resistance with temperature, dR/dT, appear as an oscillating voltage, $\delta V(t)$, which is proportional to the temperature swings, δT, in the following way:

$$\delta V = I\ (dR/dT)\ \delta T \qquad \text{(eqn 3.20)}$$

therefore the temperature swing can be determined by:

$$\delta T = \delta V/[I\ dR/dT]\,. \qquad \text{(eqn 3.21)}$$

Typically, our bias current, I, was set at 2.7 to 3.0 μA.

The factor of dR/dT was determined by static calibration. The calibration data is obtained while the temperature of the helium bath is being reduced. The vapor pressure and resistance are recorded each time the pressure changed by 0.1 mmHg. The temperature corresponding to a given pressure was found using the Cubic Spline method [Ref. 38]. The differential resistivity was calculated by making a least square best fit to an exponential in the temperature range of interest for each particular helium run. Figure 3.12 gives a sample of the data. The exponential resistance was motivated by the semiconductivity energy gap activation model; and the exponential form,

$$R(T) = R(o)\ \exp[-\alpha T]$$

was convenient for the expression of differential resistivity

$$\alpha = [1/R(o)][\partial R/\partial T].$$

Table III shows the thermometer calibration constant, α, for specific temperatures used during our experiment.

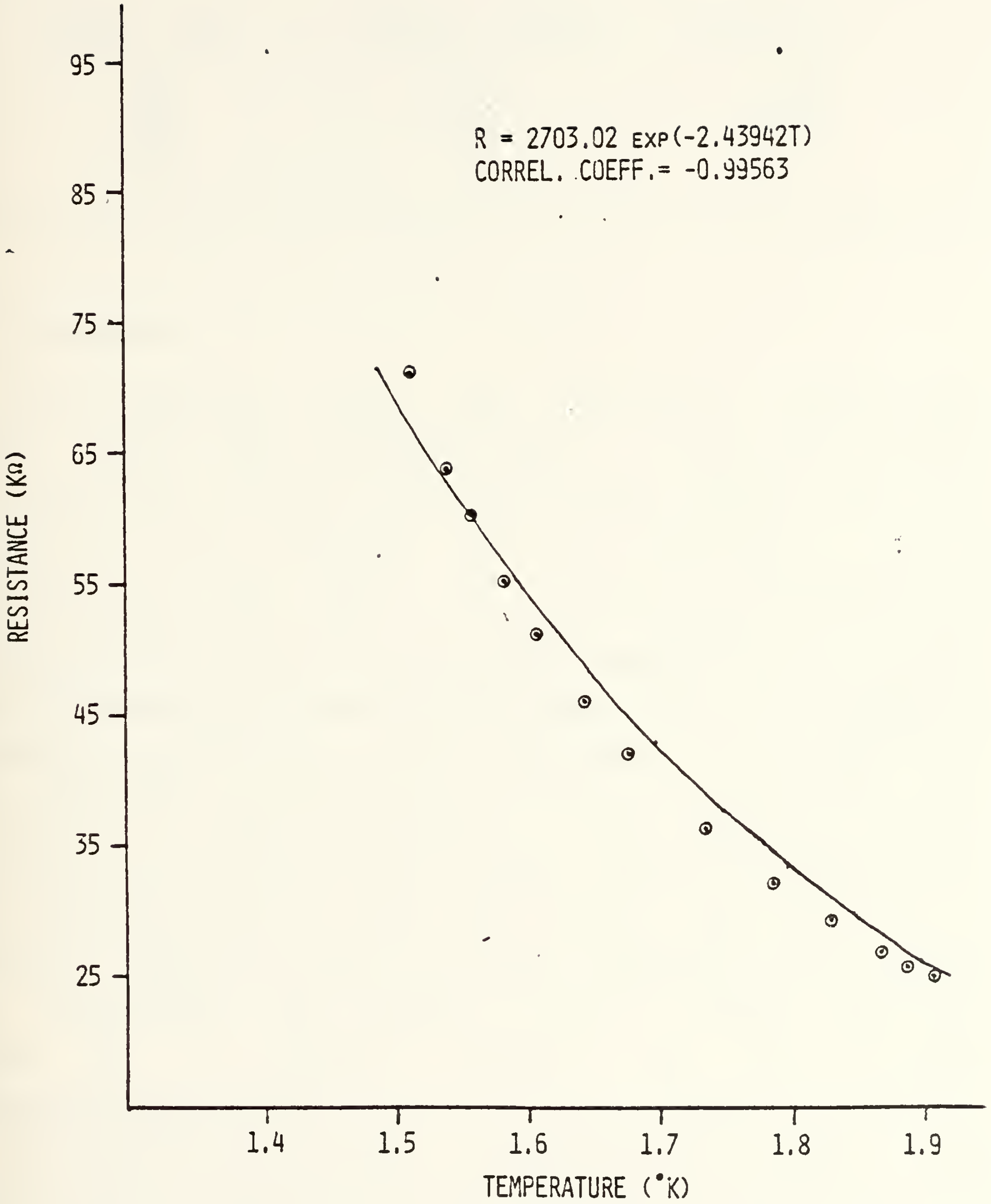

Figure 3.12 Thermometer Calibration Curve.

TABLE III
Thermometer Calibration Constant

Temp. (^{o}K)	Resist. ($K\Omega$)	α (^{o}K)$^{-1}$
1.47	81.44	-3.175
1.53	66.62	-3.387
1.65	46.11	-2.735
1.83	29.59	-2.205
1.95	23.11	-1.859

C. ELECTRONICS

Three different methods were employed to generate and detect second sound standing waves. First one electret transducer was driven and the resulting second sound was detected by the remaining electret transducer. In the remainder of this report this will be designated as Electret/Electret or E/E. The second method was to drive the heater and detect the generated sound using one of the electret transducers (Thermal/Electret; T/E). Both electret transducers were used in data gathering. After sufficient data had been obtained using one electret transducer as a reciever the output was shifted to the remaining electret transducer and the data was obtained using that combination. The third method again drove the heater, but this time the thermally generated second sound was detected by its associated temperature oscillations using a carbon resistor, biased by a constant current, as the receiver (Thermal/Thermal; T/T).

All three methods used a sinusoidal drive signal. Due to the size and symmetry of the electret transducers and the heater that generated second sound waves, all wave forms were assumed to be planar, and the harmonicity of the detected modes varified that assumption.

In the following sections on transducer electronics, Electret/Electret, Thermal/Electret, and Thermal/Thermal the HP-3325A Synthesizer/Function Generator and the EG&G Princeton Applied Reasearch (PAR) Model-5204 Lock-in Anyalyser are the output and input respectively of the data acquisition system which is discussed briefly in the RESULTS chapter.

1. Electret/Electret

Figure 3.13 is a block diagram of the electronic set up for the electret drive, electret pick up mode of generating and detecting second sound.

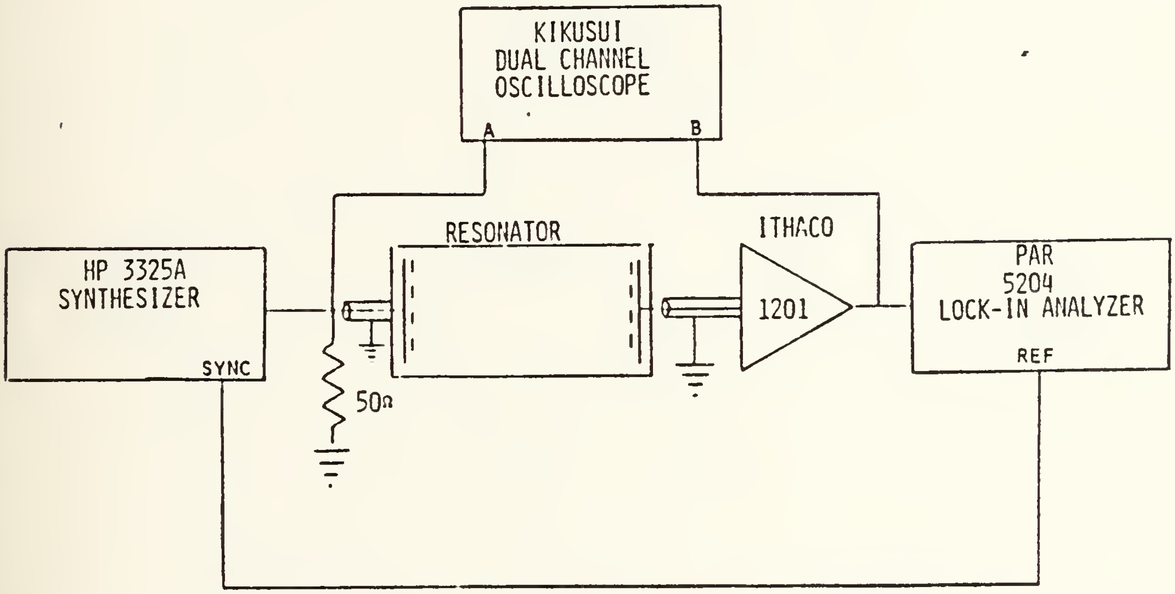

Figure 3.13 Electret/Electret Electronics Block Diagram.

The drive signal is taken from a HP-3325A Synthesizer/Function Generator. The signal passes thru a nominal 50 ohm resistor which ensures drive signal amplitude

matching between synthesizer output and the input to the electret driver. The drive signal is monitored on a KIKUSUI Dual Channel Oscilloscope Model COS-5060.

The detected or output signal passes thru an ITHACO Model-1201 Low Noise Preamplifier and again is monitored on the remaining channel of the oscilloscope. The output signal continues to the lock-in anyalyser.

2. Thermal/Electret

Figure 3.14 is a block diagram of the electronic configuration for thermal drive, electret pick up mode of generating and detecting second sound.

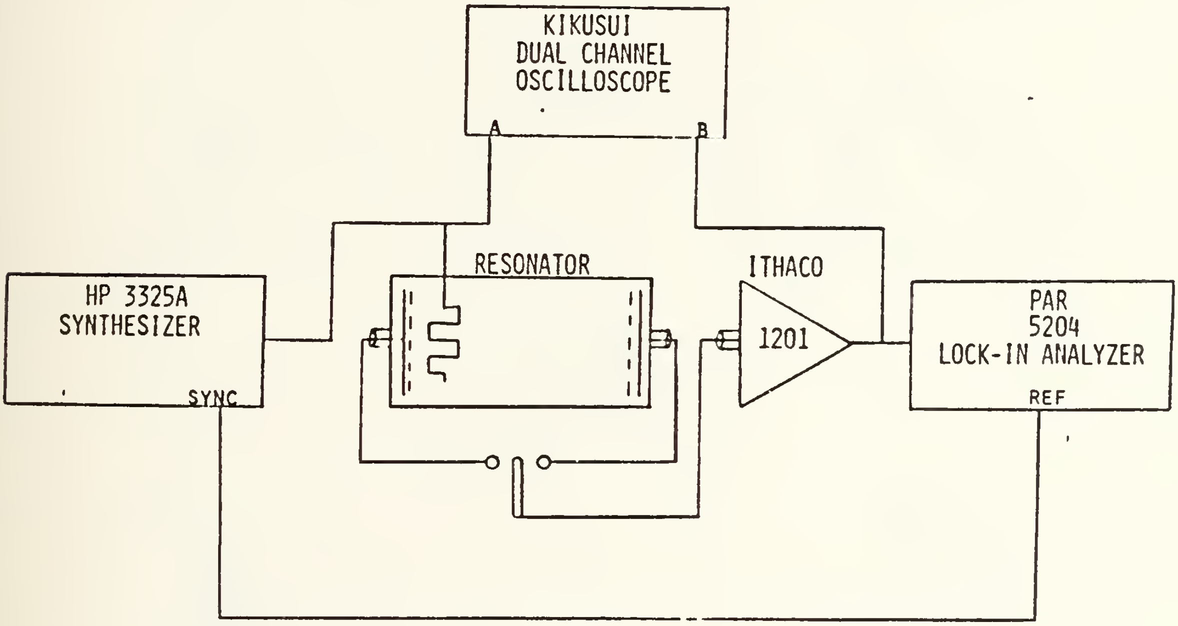

Figure 3.14 Thermal/Electret Electronics Block Diagram.

As can easily be seen by comparing the two block diagrams, there is little difference in the electronics

between Electret/Electret and Thermal/Electret. In fact the only difference is in the drive portion of the circuit. In the T/E method the nominal 50 ohm resistor has been replaced by the 63 ohm drive heater which again maintains drive amplitude continuity. Because the heating is quadratic in the heater current (see Transducer Section) the lock-in which was referenced to the synthesizer frequency was operated in the 2nd harmonic mode.

3. Thermal/Thermal

Figure 3.15 is a block diagram of the electronic set up for the thermal drive, thermal pick up mode of generating and detecting second sound.

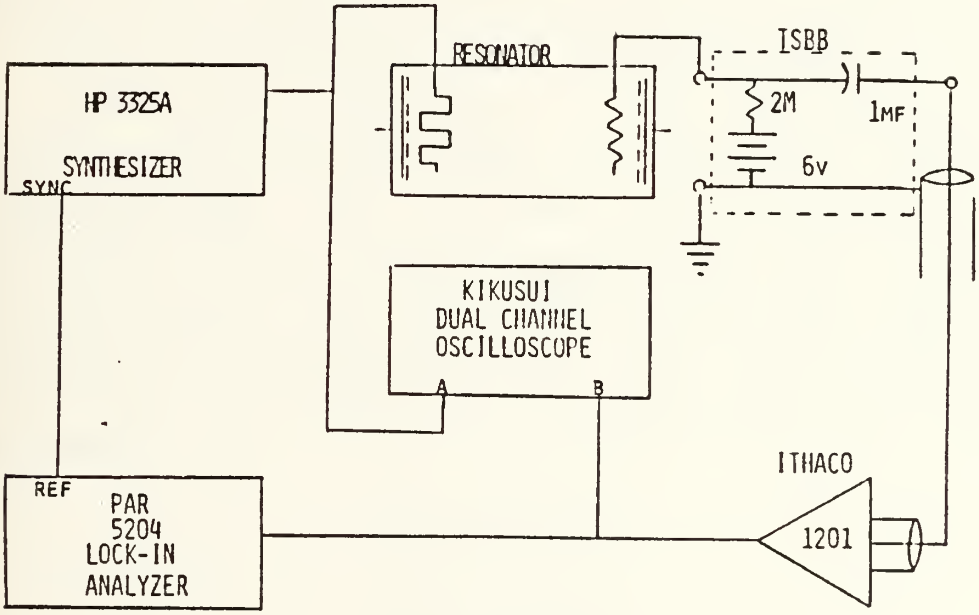

Figure 3.15 Thermal/Thermal Electronics Block Diagram.

The electonics for the drive signal is identical to that of the Thermal/Electret mode. The second sound signal

is detected by means of the induced temperature swings in a carbon resistor biased by a constant current (2.7 micro-amps). The Thermal Sound Bias Box (TSBB) is the constant current source for the detection (thermometer) resistor. The TSBB also has a DC blocking capacitor in the output circuit to ensure that only the AC component of the signal is passed to the preamplifier. From the preamplifier the signal is monitored by the oscilloscope and the lock-in simultaneously.

4. Line Loss

When the output signal is electret generated, i.e. T/E and E/E, the electret voltage output is degraded due to the capacitance of the lead between the top of the probe and the preamplifier. Figure 3.16 is an equivelent circuit representing the detecting electret and the preamplifier.

C(e) is the capacitance of the electret transducer which is detecting the signal. For simplicity we have defined the effective transducer to include the capacitance of the transducer (85 pf) plus the capacitance of the coaxial cable (155 pf) which brings the signal to the top-plate of the probe. C(i) and R(i) are the input capacitance and resistance of the preamplifier. C(l) is the capacitance of the coaxial lead connecting the probe (electret) and the preamplifier.

C(i)= 49 pf
C(l)= 35 pf

Total= 84 pf

These values were measured using a HP-4261A LCR Meter, therefore,

$$Vg(mv) = V(output)(mv)\ [(C(e) + 84)/C(e)].$$

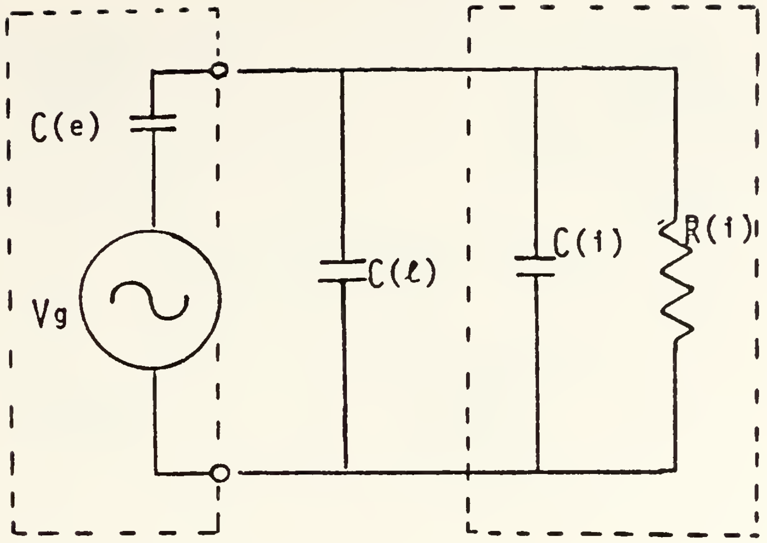

Figure 3.16 Line Loss Circuit Diagram.

Because a precise knowledge of the values of these capacitances was so important to the interpretation of the voltage measured at the lock-in in terms of the voltage at the defined "end" of the electret transducer, a special technique was used to measure the electret transducer capacitance while the system was under true operating conditions i.e. between 1 and 2 °K. This was accomplished by setting up the circuit in Figure 3.17. This circuit maintained a relatively fixed voltage while the frequency was varied from 1kHz to 10kHz. The voltage (RMS) and the current were recorded at each frequency and the capacitance at each frequency was determined using the following relationship:

$$C=I/2\pi fV$$

The capacitance for all frequencies were averaged together to give the operating condition capacitance. The typical electret capacitance, including the coaxial cable to the

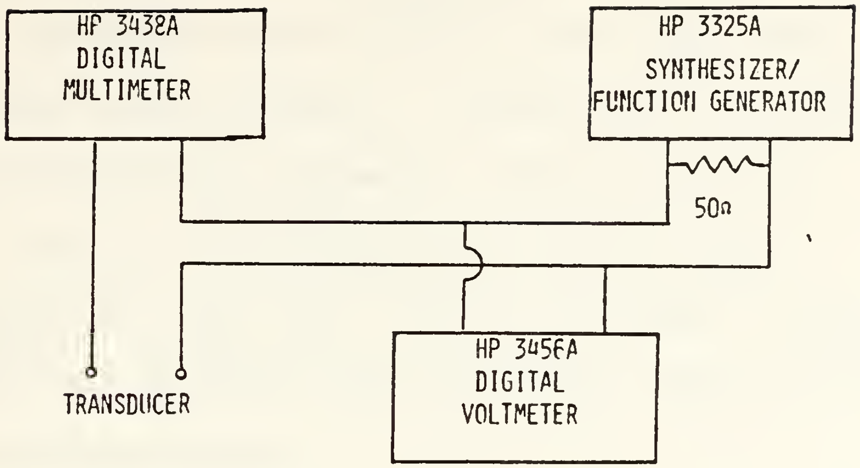

Figure 3.17 Operating Capacitance Measurement Circuit.

top-plate was 241.35 ± 0.41 pf, where the error is the standard deviation of the measurements over the range of frequencies.

5. Calibration of the Synthesizer

It was important to determine any correction between computer bus specified drive output and actual voltage which appeared at the proper device (heater, electret, etc.). It was important to know this correction not only as a fuction of drive voltage (10 to 150 mv), but also as a function of drive frequency (200 to 1500 Hz).

First it was noted that there was less than .02% difference in actual output voltage over the frequency range of concern. Next a plot of bus specified drive voltage verses actual applied voltage was made, and using the method linear regression, the following line equations for synthesizer output were developed.

1) Synthesizer driving heater (T/E & T/T)

V(actual) = 1.04887 V(syn) + 0.029067 .... r = 0.9999937

2) Synthesizer using nominal 50-ohm load (E/E)

V(actual) = 0.99319 V(syn) - 0.28676 .... r = 0.9999920

where r is the linear regression correlation value.

(Note: All voltages are in milli-volts)

These equations where then used in the data reduction to convert the bus specified voltage to the actual voltage.

6. In-Line Filters

Filters in the ITHACO preamplifier and the PAR lock-in analyser were utilized to minimize extraneous noise sources due primarily to pump induced vibrations.

The 30 Hz High Pass filter and the 10kHz Low Pass filters were utilized on the preamplifier while the 50 Hz High Pass filter was utilized in the lock-in anylyzer.

As the 50 Hz high pass of the lock-in dominated the low frequency response and the 10kHz low pass of the preamplifier dominated the high frequency response, the maximum system reciever response was expected at a frequency which was the geometric mean of these values, or about 707 Hz. This was observed experimentally. At 700 Hz the lock-in output was 0.9997 of the calibrated input. At the lowest frequency of interest (400 Hz) this transfer function dropped to 0.9971 while at the highest frequency of concern (1.6 kHz) it was 0.9914. These attenuation functions were considered negligible in the interpretation of the results.

IV. RESULTS

A. PROCEDURES

1. Cooldown

Prior to the commencement of cooldown, the inner vacuum jacket is purged with air and then evacuated to less than 2 mmHg. This is important to ensure that no helium gas is in the inner jacket.

The probe is placed in the experimental area. Liquid nitrogen is then added to the outer jacket to commence the cooldown. The experimental area is then evacuated to 80-100 mmHg.

The temperature of the experimental area is monitored by three different and independent methods. Quantitative results were obtained by monitoring the fundamental or a harmonic frequency of the air filled resonator. This is accomplished by using the HP 3580A Spectum Analyzer to drive and pick-up the resulting signal in the Electret/Electret mode. The following two equations

1) $f(n) = nc/2L$

2) $c^2 = \gamma RT/M$

results in

$$T(^\circ K) = 2.48 \times 10^{-5} f(n)^2/n^2$$

where the constant is a result of the length of the resonator and the previously presented thermodynamic constants.

The remaining two methods only present trends. The first is monitoring the attached carbon resistor on the probe. Although this did not provide quantitative data during the liquid nitrogen cooldown phase, it was very useful in determining the point at which we expected the liquid helium to collect in the dewar during the transfer.

As the temperature decreases the resistance increases. The remaining method is to monitor the pressure in the inner dewar. Since the volume of the inner dewar remains constant, the pressure will drop as the temperature drops in accordance with the Ideal Gas Law.

2. Liquid Helium Transfer

Once the temperature in the experimental area reaches approximately 85°K the transfer of the liquid helium may commence. This transfer of the liquid helium from the shipping dewar to the inner dewar is accomplished via a transfer tube.

The transfer tube is a double walled stainless steel tube. A vacuum is maintained between the two walls to minimize heat conduction to the liquid helium.

Immediately prior to the transfer, the transfer tube is purged with helium gas. This minimizes the possibility of air and water vapor in the tube condensing and forming a plug in the line, thereby resticting or completly stopping the transfer.

The inner dewar is also brought to atmosheric pressure by bleeding in helium gas thru the helium purge valve. Once the inner dewar is at atmospheric pressure, one end of the transfer tube is placed in the shipping dewar while the other end is placed in the helium recieving tube on the top of the probe. The shipping dewar is then pressurized to approximately 3 psig using helium gas. This commences the transfer.

3. Pump Down

Once the desired liquid helium level is obtained, keeping in mind that during the pump down the liquid helium level will drop by 1/3 to 1/2 of its original level at the commencement of pump down, the shipping dewar is vented concluding the

transfer. The transfer tube is removed from the shipping dewar and the helium recieving tube. The helium recieving tube is "capped" using a rubber stopper and the helium purge valve is closed.

The vapor pressure of the helium must be reduced in order to reduce the liquid helium temperature. This is accomplished by using the 15 cfm vaccum pump refered to in Chapter III to evacuate the inner dewar. The isolation cross-connect valve in the manostat is opened allowing the pressure inside and outside the membrane to remain equal, thereby allowing an unimpeded flow path from the inner dewar to the vaccum pump. Once the desired pressure/temperature is obtained, the isolation cross-connect valve on the manostat is shut allowing the manostat to control the pressure.

B. DATA AQUISITION

Data was obtained and analyzed by means of a computaional algorithm and a data aquisition system. The system utilized an HP-85 desk-top computer, an HP-3325A Synthesizer/Function Generator, an EG&G-5204 Lock-in Anylyzer and an HP-3497A Data Aquisition/Control Unit. The system automatically measures and tracks the center frequencies, amplitudes and quality factors (Q) of up to 9 acoustical resonances. A typical spectrum was shown in Figure 3.9.

An in depth explination of the basis for the data aquisition system is contained in a Masters Thesis by D. Conte [Ref. 45]. Due to the fact that Conte describes a system in air and uses a thermistor for temperature monitoring, slight modifications where required to the program for the HP-85. This program is listed in Appendix A.

A short and very basic discription of the aquisition system follows. The HP-85 computer directly controls all of the equipment, with the exception of the Lock-in Analyzer, via the Hewlett Packard Interface Bus (HPIB; IEEE Standard 488-1975). The computer sends a value for frequency and amplitude to the HP-3325A Synthesizer/Function Generator, which causes an excitation of the acoustic resonances. The EG&G-5204 is phased-locked to the HP-3325A and generates a D.C. voltage which is proportional to the Pythagorian sum of the amplified in-phase and quadrature components of the signal. This analog amplitude is sent to the HP-3497A which, when interrogated, sends via the HPIB, a digitization of the voltage level.

This system provided excellent results in a minimum of time. The chi-squared minimization search utilized in the program yielded precisions of better than 0.1 percent in Q, 0.01 percent in amplitude and 0.1 ppm in frequency.

C. DATA REDUCTION

Our computer controlled data acquisition system compiles, on magnetic tape, all necessary electrical reading for electret-electret (E/E) and thermal-electret (T/EA and T/EB) configurations. The computer program provided in Appendix B is then used to process this formatted "raw" data, which is provided in Appendix C. The sensitivities (MA and MB) of our slit-electret transducers are then computed using equations 3.5 to 3.10.

From the reciprocity computation of transducer sensitivities we are able to determine the corresponding temperature oscillation r.m.s. amplitude (δT_r), which is the ratio of output voltage to transducer sensitivity. The temperature oscillation that defines the upper limit (δT_u) is computed from equation 3.19. The ratio of δT_u to δT_r is an

extremely important quantity in our experiment since its value makes a definite statement about the validity of our computed thermal transducer sensitivities.

It should be pointed out that the measurements obtained for E/E and T/E contain their own values of frequency, amplitude and quality factor, with each data set occurring at essentually the same temperature. For our calculations the average frequency and temperature are used. An assemblage of reduced data is provided in Appendix D.

When looking at the output of the reduced data of Appendix D you will find the resonant modal number listed first. Recall that the necessary electrical readings for E/E, T/EA and T/EB were all taken at slightly different temperatures and therefore at slightly different center frequencies. The average temperature and frequency used for each calculation set is provided along with their standard deviation. The next item is the temperature oscillation amplitude calculated by the reciprocity method, followed by the amplitude of the temperature oscillation which has been determined to be the upper limit. The ratio of these two amplitudes is also provided at the end of the printout. Recall that the upper thermal oscillation by the thermophone principle required us to drive the heater and take the output from either electret A or B. In our calculations the output was taken from electret A; however, the upper limit has also been calculated using the output of electret B and the difference between the two is listed (Ua-Ub). Finally, the "slit-electret" sensitivities are provided for side A and B.

D. ERROR ANALYSIS

The final section of this chapter will deal with the inherent errors that are a part of every experiment. The

magnitude of these errors must be reasonable and scrutinized with our final results to determine the strength of our analysis. In order to determine the accumulated error which exists in our calculated thermal transducer sensitivities we must recall equation 3.5 :

$$M(A)M(B) = [d^2\pi U(II) Cp\rho/16][V(m)n/(V(s)QfCT)] .$$

The factors that carry significant inherent errors are second sound speed U(II), helium density ρ , specific heat of helium Cp, frequency f, temperature T, electret capacitance C, quality factor Q and all voltages.

From the UCLA thermodynamic data [Ref. 21] we find that second sound speed is known to within 0.1% , helium density is known to within 0.45% and the specific heat is known to within 0.2% . This gives a total error for these three parameters of

$$[(0.001)^2 + (0.0045)^2 + (0.002)^2] = 0.5\%.$$

From our assembled data we have found that the accuracy of the remaining parameters is as follows :

frequency	0.6%
temperature	0.3%
capacitance	0.2%
quality factor	0.6%
voltages	0.5% x sqr(8) = 1.4%

The sqr(8) occurs because when equation 3.5 is used to determine the absolute sensitivity of either transducer A "or" B there are eight factors of voltage required. When all of the above errors are combined the resulting total error is found to be 1.7% .

V. CONCLUSIONS

A. VALIDITY OF RECIPROCITY IN A QUANTUM FLUID

The absolute sensitivities of the slit-electret transducers were determined using the Reciprocity Theorem. We were able to make precise measurements of temperature, resonant frequency, amplitude and quality factor. Invoking the assumption that all of the oscillatory heat dissipated in the heater was radiated as second sound, the amplitude of the upper bound for temperature oscillations was calculated.

The ratio of the temperature oscillation for the upper bound to that of reciprocity is plotted as a function of mode number at a temperature of $1.53\ ^{o}K$ and is shown in figure 5.1 as circled data points. The dashed line exists only as a guide to the eye.

In calculating the circled data points of Figure 5.1 it was assumed that the thermal driver (webbed heater) was optimally positioned directly against the electretted endcap. Since in reality this would electrically short the electret and heater, the heater was intentionally offset by a distance that was roughly measured to be 2mm. We can assume that when our heater is driven the resulting response is reduced by a factor of

$$\cos(2n\pi/L)$$

which accounts for the lower effective thermal impedance, where L = 50mm, is the resonator length. At any temperature, the ratio of the amplitude of oscillation for any two modes must equal a constant such that

$$\cos(n\pi x/25)/\cos(m\pi x/25) = C\ ,$$

where, for our data, C is obtained by averaging the ratio of upper limit to reciprocity temperature amplitude oscillations for modes 2 and 6 at all temperatures.

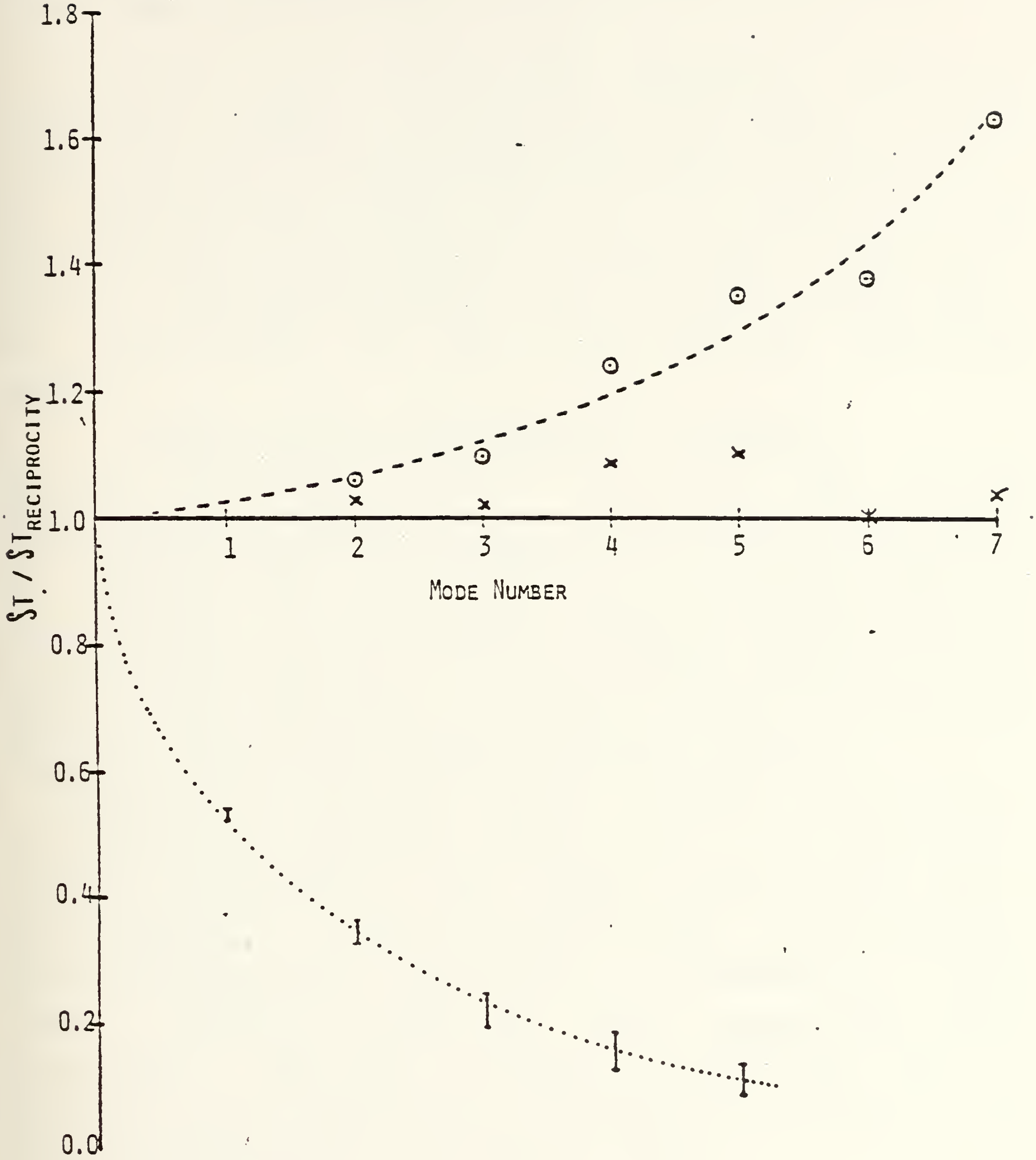

Figure 5.1 ST /ST$_r$

]

This gives us

$$C = 1.217 \pm 0.05 \ .$$

When the above transcendental equation is solved for "x" for modes 2 and 6 we find that

$$x = 1.7\text{mm}$$

which indeed supports our rough measurement of heater displacement (2mm). So we see that the effect of this heater offset is to reduce the circled data of Figure 5.1. The corrected data points, the X's, in Figure 5.1 are obtained using a displacement of 2mm for ease of calculation since the difference observed using 1.7mm is insignificant. This then requires the use of the following correction factor:

$$\delta T\,(\text{corrected}) / \delta T\,(\text{circled}) = \cos(n\pi/25) \ .$$

This data is shown in Figure 5.1 and we see that the two methods are in excellent agreement. It is important to note that Table IV shows only a sample of corrected data taken at T = 1.53 °K. In actuality, Figure 5.1 illustrates the corrected data for data obtained at five different temperatures and for many more data points. As indicated in the Table, a total of twelve data points were used for each mode to obtain these truly representative ratio values.

The bars in the lower portion of figure 5.1 represent the ratio of the temperature oscillation for the lower bound to that of reciprocity. The thermal inertia of the resistive thermometer, Kapitza resistance [Ref. 22] and geometry make the temperature oscillation by thermometry a lower limit. Figure 5.1 shows that these effects are indeed significant. Data which involved the lower limit was not required for the quantitative verification of the utility of the reciprocity method in a quantum fluid.

TABLE IV

Heater Displacement Correction (T = 1.53 °K)

mode	# pts	cos(nπ/25)	$\delta T_u/\delta T_r$	corrected $\delta T_u/\delta T_r$
2	12	0.9686	1.057	1.024
3	12	0.9298	1.109	1.031
4	12	0.8763	1.241	1.087
5	12	0.8090	1.195	0.967
6	12	0.7290	1.263	0.921
		average >>>	1.173 >>>	1.006

B. SENSITIVITY OF SLIT-ELECTRET TRANSDUCERS

By assuming that the temperature oscillation amplitude calculated from the thermophone heat current is the true oscillation amplitude, it is possible to use the temperature amplitude measured by the reciprocity method to determine the specific acoustic transfer impedance, or the reciprocity constant M'(T) which is the inverse of its square root. The points plotted in figure 5.2 and connected by the dashed straight line are the values of M'(T) calculated from the UCLA thermodynamic data [Ref. 21] and shown previously in Figure 2.2.

The equation for the dashed line is a least squares fit to the data between the temperatures of 1.2 to 1.9 °K :

$$M'(T) = 2.176\ T - 1.775$$

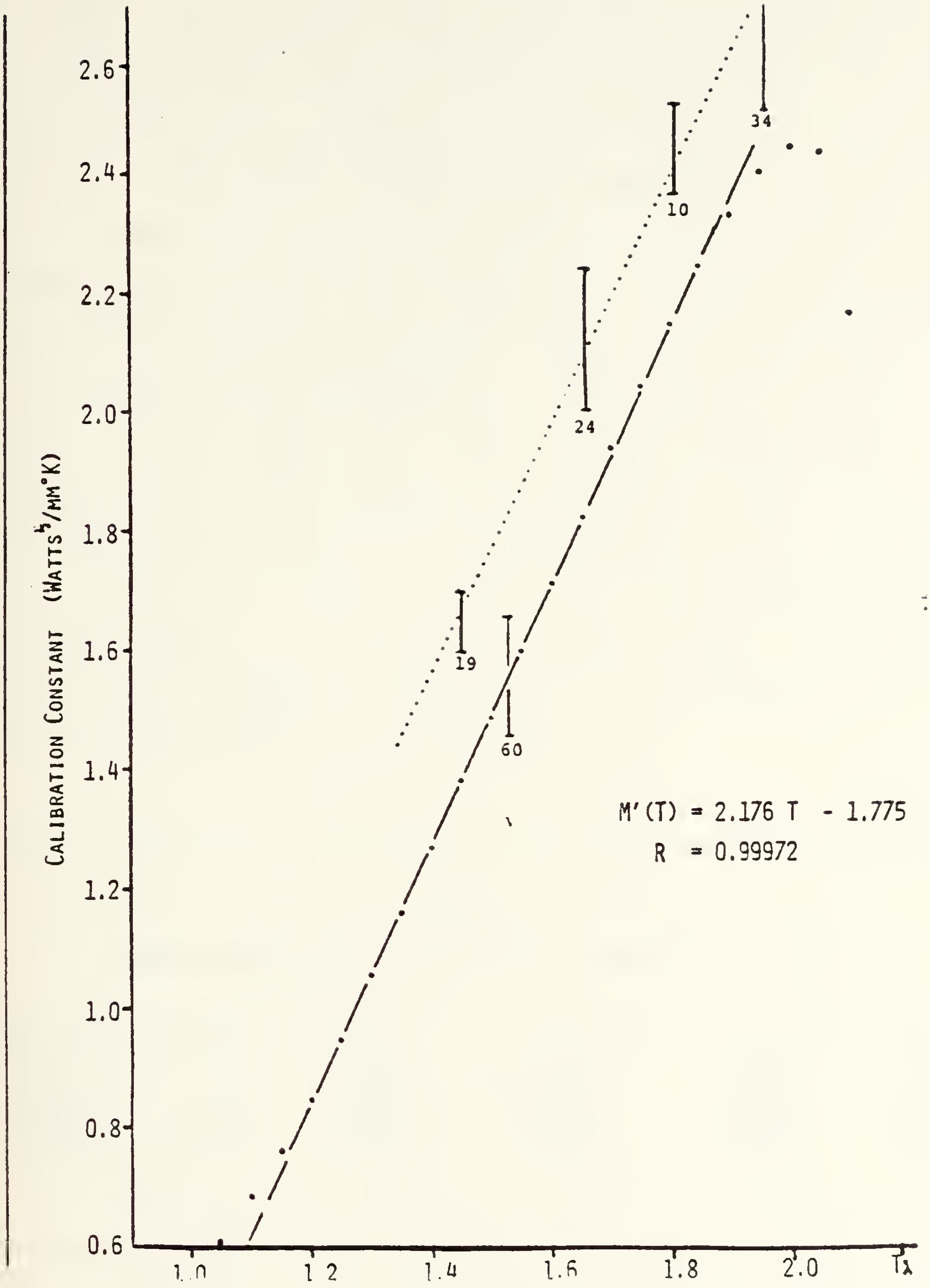

Figure 5.2 Experimental/Theoretical Determination of M'.

and the units are (watts$^{1/2}$/mm- ^{o}K). The mean square deviation of these fifteen (15) points from that line is less than 0.7%. The five bars are the values of M'(T) based on all of the thermal and reciprocity measurements made at those temperature. Table V is a compilation of the data in Appendix C used to prepare the experimental points in Figure 5.2. Due to the intentional redundancy in our technique we were free to mix various E/E and T/E data sets at any given temperature. The choice was random and the number of "mixtures" for any given temperature and mode number is given in the Table. The number under the error bars gives the total number of points used to average M' at that temperature. The bars are two standard deviations tall, centered around the average. The dotted line connecting four of the five bars is a guide to the eye. At the present time we have no explaination for the approximate 10% discrepancy shown in Figure 5.2, but it does appear to be systematic and outside the limits of our uncertainty in the experimentally measured quantities.

TABLE V

Experimental Calibration Constant Data

Temp(^{o}K)	#pts	$\int T_u/\int T_r$	M'(+)	M'(avg)	M'(-)
1.453	19	0.844	1.695	1.638	1.594
1.531	60	1.000	1.652	1.556	1.454
1.602	24	0.871	2.246	1.842	1.997
1.808	10	0.885	2.519	2.159	2.365
1.959	34	0.902	2.869	2.410	2.500

In conclusion, we have shown, for the first time, that it is possible to make absolute acoustical measurements of temperature oscillations in superfluid helium using the reciprocity technique. Also, in addition to illustrating an excellent application of the Conte system of precise acoustical data aquisition, we were successful in measuring absolute temperature excursions as small as 10^{-10} $^{o}K/(Hz)^{1/2}$.

A sample of the transducer sensitivities as a function of temperature and mode number is shown in Figure 5.2. All reduced sensitivities are given in Appendix D. It is worth noting that these sensitivities are a factor of 2.3 (ie, 240pf/85pf) smaller than the true sensitivity since the "effective transducer" was defined to include the coax cable which brought the signal to room temperature [see Chapter III (C.4)].

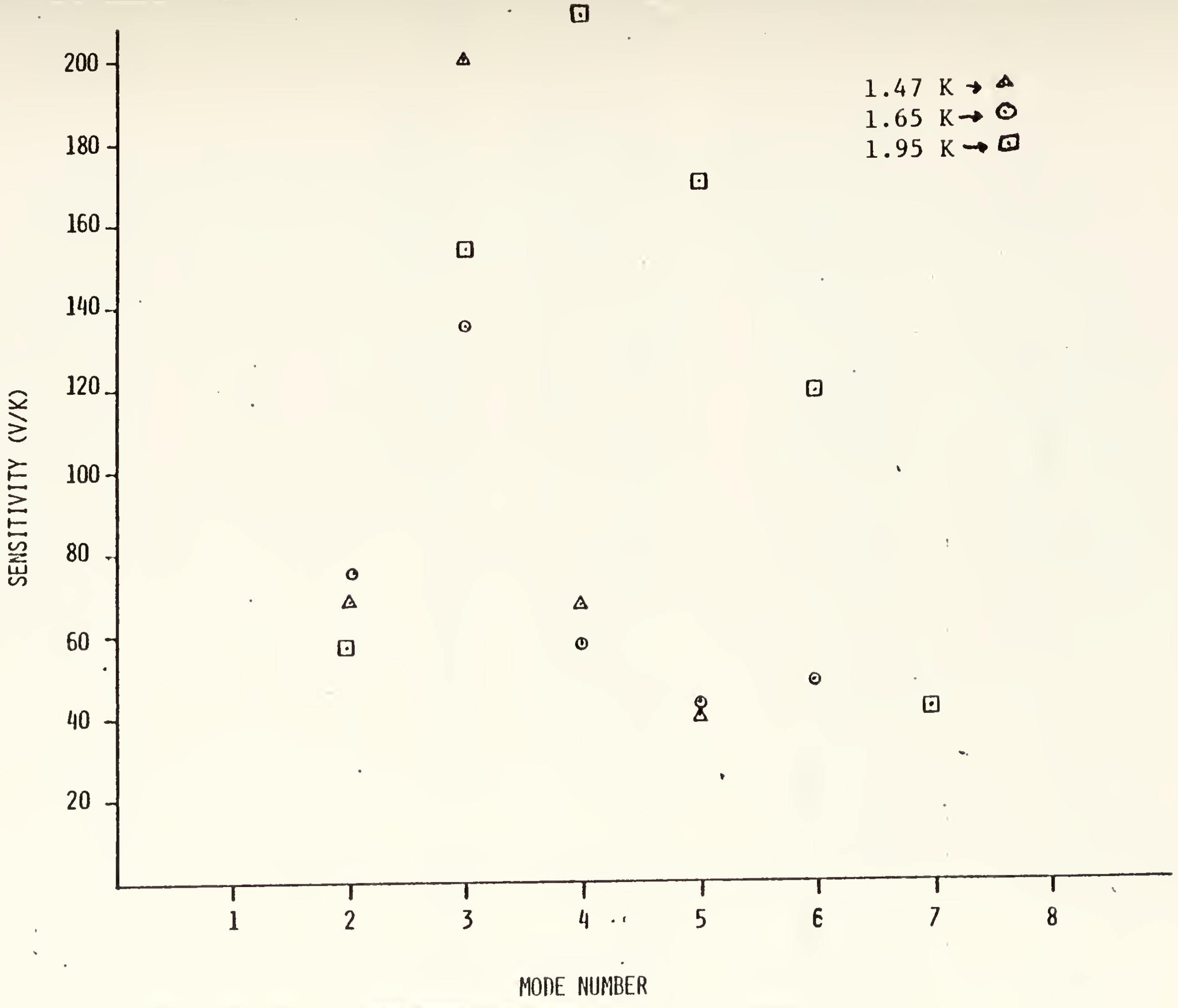

Figure 5.3   Electret Sensitivity vs Temperature.

APPENDIX A

DATA AQUISITION PROGRAMS

1) BJ#2....... Extracts necessary electrical readings; calculates Q, amplitude and center frequency; formats the output as raw data (Appendix C).

2) TMRCAL..... Monitors pressure and thermometer resistance; converts pressure to temperature; provides necessary information to determine thermometer differential resistivity.

3) COOLDN..... While monitoring a specified resonant mode, this program outputs helium temperature due to the change in sound speed during cooldown.

4) P vs t..... Monitors the performance of our pressure (temperature) regulator.

```
1 DIM F4(300),A(300),C(100),X8(26),X7(26),E1(25),E2(25),E6(25),E7(25)
2 CLEAR @ PRINTER IS 2 @ OUTPUT 722 ;"F4M6"
3 DISP "REMOVE PROGRAM TAPE AND INSTALL DATA TAPE" @ BEEP
4 DISP "WHEN COMPLETED, ENTER 1"
5 INPUT Y
6 IF Y=1 THEN 7 ELSE CLEAR @ BEEP @ GOTO 3
7 CLEAR @ BEEP @ DISP "DO YOU DESIRE TO ERASE AND REWIND TAPE?(Y/N)"
8 INPUT K$@ IF K$="N" THEN 11 ELSE 9
9 ERASETAPE @ GOTO 93
10 CREATE Z$,850,88 @ REWIND @ GOTO 12
11 CLEAR @ BEEP @ GOTO 97
12 CLEAR @ BEEP @ GOTO 8992
13 SETTIME 0,0
14 DISP "DO YOU WANT TO SKIP DIRECTLY TO MEASURE?(Y/N)"
15 INPUT K$
16 IF K$="N" THEN 83 ELSE 17
17 CLEAR @ BEEP
18 DISP "Enter amp of driving freq in mv (=<3500)RMS"
19 DISP "DECIMAL VALUES ARE NOT PERMITTED"
20 INPUT A ! amp of freq
21 IF A>3500 THEN CLEAR @ BEEP @ GOTO 18
22 FOR N=1 TO 9
23 A8(N)=A
24 NEXT N
25 CLEAR @ BEEP
26 DISP "Enter largest value of amp ever desired (=<3500mv RMS)"
27 INPUT A1 ! max future amp
28 IF A1>3500 THEN CLEAR @ BEEP @ GOTO 26
29 ! these are the values to set up the 3325A
30 A$=VAL$(A)
31 A2$="AM"
32 A3$="MR"
33 OUTPUT 717 ;A2$,A$,A3$
34 CLEAR @ BEEP
35 DISP "Enter full-scale sensitivity setting from the 5204 in volts=FSS/(PREAMP
 GAIN*MULTIPL)"
36 INPUT A5 ! SENSITIVITY SETTING
37 CLEAR @ BEEP
38 DISP "Set and enter new time constant (in milli-sec)"
40 INPUT Y
41 T1=Y
42 CLEAR @ BEEP
43 DISP "How many modes do you desire to track (MAX OF 9)"
44 INPUT M ! NUMBER OF MODES
45 FOR N=1 TO M
46 CLEAR @ BEEP
47 DISP "What is center freq for mode ";N
48 INPUT F6(N) ! CENTER FREQ
52 CLEAR @ BEEP
53 DISP "What is the Q for mode ";N
54 INPUT Q(N)
55 I(N)=24
56 CLEAR @ BEEP
57 DISP "What is the amplitude of the center freq for mode ";N
58 INPUT A6(N)
59 CLEAR @ BEEP @ A6(N)=A6(N)/A5
60 NEXT N
61 DISP "I am working on standard dev, # of pts, & variance "
62 ! From 63 to 82 is the calc of the noise, st. dev., and the number of pts. us
ed.
```

```
63 G,W=0 @ H1$="HZ" @ H2$="FR"
64 F=(F6(2)-F6(1))/4+F6(1)
65 F4$=VAL$(F)
66 OUTPUT 717 ;H2$,F4$,H1$
67 WAIT T1*12+100
68 OUTPUT 709 ;"VT1"
69 WAIT 1000
70 FOR N=1 TO 100
71 ENTER 709 ; A(N)
72 W=W+A(N)
73 NEXT N
74 W=W/100
75 FOR N=1 TO 100
76 S=(A(N)-W)^2
77 G=G+S
78 NEXT N
79 G=A5*SQR(G/99)
80 W=W*A5
81 PRINT "The mean is ";W;" and the standard dev is ";G
82 GOTO 8100
83 CLEAR @ BEEP
84 DISP "Enter lower freq"
85 INPUT F1 ! lower freq
86 CLEAR @ BEEP
87 DISP "Enter upper freq"
88 INPUT F2 ! upper freq
89 IF F2<=F1 THEN CLEAR @ BEEP @ GOTO 87
90 T=1/(4*((F2-F1)/256)) ! time constant
91 CLEAR @ BEEP
92 GOTO 101
93 DISP "DATA FILE NAME.";
94 INPUT Z$
95 GOTO 10
97 DISP "ENTER NAME OF DATA FILE"
98 INPUT Z$@ GOTO 12
101 DISP "Set time constant on 5204 at ";T;" or smaller"
111 DISP "When complete, enter value set (in Milli-sec)"
121 INPUT T1
131 IF T1>T*1000 THEN CLEAR @ BEEP @ GOTO 101
141 CLEAR @ BEEP
151 DISP "Enter amp of driving freq in mv (=<3500)RMS"
161 DISP "DECIMAL VALUES ARE NOT PERMITTED"
171 INPUT A ! amp of freq
181 IF A>3500 THEN CLEAR @ BEEP @ GOTO 151
182 FOR N=1 TO 9
183 A8(N)=A
184 NEXT N
191 CLEAR @ BEEP
201 DISP "Enter largest value of amp ever desired (=<3500mv RMS)"
211 INPUT A1 ! max future amp
221 IF A1>3500 THEN CLEAR @ BEEP @ GOTO 201
230 ! these are the values to set up the 3325A
231 A$=VAL$(A)
232 A2$="AM"
233 A3$="MR"
240 OUTPUT 717 ;A2$,A$,A3$
241 WAIT 200
251 F3=CEIL((F2-F1)/256) ! smallest int >= bandwidth
252 ! SEARCH
253 ! SEARCH
```

```
254 ! SEARCH
261 ! next group sends freq to 3325A, and gets amp from 3497A
269 CLEAR
270 DISP "I am working in SEARCH"
271 FOR N=0 TO 256
281 F4(N)=F1+N*F3
282 ! F4(N) is freq sent
290 F4$=VAL$(F4(N))
291 H1$="HZ"
292 H2$="FR"
300 OUTPUT 717 ;H2$,F4$,H1$
310 WAIT 4*T1+100
320 OUTPUT 709 ;"VT3"
330 ENTER 709 ; A(N)
350 NEXT N
351 ! F5 AND F6 ARE SCALE FACTORS
352 BEEP
360 F5=F1-.1*(F2-F1)
370 F6=F2+.1*(F2-F1)
380 GCLEAR @ CLEAR
390 SCALE F5,F6,-.1,1.2
400 XAXIS 0,1000,F1,F2
410 YAXIS F1,.1,-.1,1.2
411 FOR N=0 TO 256
413 PLOT F4(N),A(N)
414 NEXT N
415 DISP "DO YOU DESIRE A COPY? (Y/N)" @ BEEP
416 INPUT K$
417 IF K$="N" THEN 477 ELSE 418
418 GCLEAR @ CLEAR @ BEEP
419 DISP "ENTER FIGURE # TO BE PRINTED"
420 INPUT L$
421 PLOTTER IS 705
422 PEN 1
423 SCALE F1-.1*(F2-F1),F2+500,-.3,1.3
424 XAXIS 0,100,F1,F2
425 YAXIS F1,.1,0,1.2
426 PEN 2
427 FOR N=0 TO 256
429 PLOT F4(N),A(N)
430 NEXT N
431 PENUP @ PEN 1
432 LDIR 0,SIN(90) @ PENUP
433 FOR X=F1 TO F2 STEP 200 @ PENUP
434 MOVE X,-.13
435 LABEL VAL$(X)
436 NEXT X @ PENUP
440 LDIR 0
441 FOR Y=0 TO 1.2 STEP .1 @ PENUP
442 MOVE F1-.05*(F2-F1),Y
443 LABEL VAL$(Y)
444 NEXT Y @ PENUP
450 LDIR 0 @ PENUP
451 MOVE F1+(F2-F1)/3,-.21
452 LABEL "FREQUENCY IN HZ"
453 LDIR 0 @ PENUP
454 MOVE F1,-.3
455 LABEL "PLOT OF RELATIVE AMPLITUDE VS FREQUENCY (FULL SPECTRUM)"
456 LDIR 0,SIN(90) @ PENUP
457 MOVE F1-.08*(F2-F1),.3
```

```
458 LABEL "RELATIVE AMPLITUDE"
459 LDIR 0 @ PENUP
460 MOVE F1+200,1.2
461 LABEL "FIGURE ";L$
462 PENUP
476 PLOTTER IS 1
477 CLEAR @ BEEP
478 DISP "Do you desire to rerun exp with different parameters?(Y/N)"
480 INPUT K$
490 GCLEAR @ CLEAR @ BEEP
500 IF K$="N" THEN 510 ELSE 11
510 DISP "Enter decision point for amplitude (0 TO 1.2)"
520 INPUT A4 ! DECISION POINT
530 CLEAR @ BEEP
540 DISP "Enter full-scale sensitivity setting from the 5204 in volts=FSS/(PREAM
P GAIN*MULTIP)"
550 INPUT A5 ! SENSITIVITY SETTING
560 PRINT "Amplitude in volts";"   Frequency"
570 PRINT
580 FOR N=0 TO 256
590 IF A(N)<A4 THEN 630
600 A(N)=A5*A(N)
610 PRINT USING 620 ; A(N),F4(N)
620 IMAGE 1X,D.DDDDDDDD,10X,DDDDDD.DD
630 NEXT N
631 PRINT USING 632
632 IMAGE 3/
640 CLEAR @ BEEP
641 ! SORT
642 ! SORT
643 ! SORT
650 DISP "How many modes do you desire to track (MAX OF 9)"
660 INPUT M ! NUMBER OF MODES
670 FOR N=1 TO M
680 CLEAR @ BEEP
690 DISP "What is center freq for mode ";N
700 INPUT M(N) ! CENTER FREQ
710 CLEAR @ BEEP
720 DISP "What is freqwidth for mode ";N
730 DISP "MUST BE GREATER THAN ";2*F3 ! F3 IS BW
740 INPUT O(N) ! FREQ-WIDTH
750 NEXT N
760 CLEAR
761 ! From 770 to 960 is the first rough try for measuring (SORT)
770 FOR L=1 TO M
771 DISP "I am working in SORT for mode ";L
780 FOR N=0 TO 25
790 F4(N)=M(L)-O(L)/2+N*O(L)/25
800 F4$=VAL$(F4(N))
810 OUTPUT 717 ;H2$,F4$,H1$
820 WAIT 12*T1+100
830 OUTPUT 709 ;"VT3"
831 WAIT 50
840 ENTER 709 ; A(N)
850 NEXT N
851 BEEP
860 GCLEAR @ CLEAR
870 SCALE F4(0)-.1*O(L),F4(25)+.1*O(L),-.1,1.2
880 XAXIS 0,O(L)/10,F4(0),F4(25)
890 YAXIS F4(0),.1,0,1.2
```

```
900 FOR N=0 TO 25
920 PLOT F4(N),A(N)
930 NEXT N
940 MOVE F4(0),-.1
941 LABEL "MODE ";L;" ";F4(0);" TO ";F4(25)
942 DISP "DO YOU WANT A COPY?   (Y/N)" @ BEEP
943 INPUT K$
944 IF K$="N" THEN 987
945 GCLEAR @ CLEAR @ BEEP
946 DISP "ENTER FIGURE # TO BE PRINTED"
947 INPUT L$
954 PLOTTER IS 705
955 PEN 1
956 SCALE F4(0)-.2*O(L),F4(25)+.1*O(L),-.3,1.3
957 XAXIS 0,O(L)/10,F4(0),F4(25)
958 YAXIS F4(0),.1,0,1.2
959 PEN 2
960 FOR N=0 TO 25
962 PLOT F4(N),A(N)
963 NEXT N
964 PENUP @ PEN 1
965 LDIR 0,SIN(90)
966 FOR X=F4(0) TO F4(25) STEP O(L)/10 @ PENUP
967 MOVE X,-.13
968 LABEL VAL$(X)
969 NEXT X
970 LDIR 0 @ PENUP
971 FOR Y=0 TO 1.2 STEP .1 @ PENUP
972 MOVE F4(0)-.08*O(L),Y
973 LABEL VAL$(Y)
974 NEXT Y
975 LDIR 0 @ PENUP
976 MOVE F4(0)+.1*O(L),-.21
977 LABEL "FREQUENCY IN HZ"
978 LDIR 0 @ PENUP
979 MOVE F4(0)-.1*O(L),-.3
980 LABEL "PLOT OF RELATIVE AMPLITUDE VS FREQUENCY, MODE ";L
981 LDIR 0,SIN(90) @ PENUP
982 MOVE F4(0)-.17*O(L),.3
983 LABEL "RELATIVE AMPLITUDE "
984 LDIR 0 @ PENUP
985 MOVE F4(0)+.1*O(L),1.2
986 LABEL "FIGURE ";L$ @ PENUP @ PLOTTER IS 1
987 CLEAR @ BEEP
988 DISP "Do you want to change anything?(Y/N)"
989 INPUT K$
990 IF K$="N" THEN 1200 ELSE 1000
1000 DISP "Change sensitivity?  (Y/N)"
1010 INPUT K$@ CLEAR @ BEEP
1020 IF K$="N" THEN 1060
1030 CLEAR @ BEEP
1040 DISP "Enter new sensitivity setting"
1050 INPUT A5
1060 CLEAR @ BEEP
1070 DISP "Change freqwidth?    (Y/N)"
1080 INPUT K$@ CLEAR @ BEEP
1090 IF K$="N" THEN 1120
1100 DISP "Enter new freqwidth"
1110 INPUT O(L)
1120 CLEAR @ BEEP
```

```
1130 DISP "Change center freq?  (Y/N)"
1140 INPUT K$@ CLEAR @ BEEP
1150 IF K$="N" THEN 1180
1160 DISP "Enter new center freq"
1170 INPUT M(L)
1180 GCLEAR @ CLEAR
1190 GOTO 771
1191 ! From 1200 to 1680 is the first try at getting center freq and the Q
1200 CLEAR @ GCLEAR
1201 DISP "I am working on freq and Q for SORT mode ";L
1210 H,B1,B4,H1,H2,H3,H4=0
1220 B2,B3=50
1230 FOR N=1 TO 24
1240 IF A(N)<A(H) THEN 1280
1241 IF A(N)=A(H) THEN 1242 ELSE 1250
1242 PRINT A(N)
1250 A6(L)=A(N)
1260 F6(L)=F4(N)
1270 H=N
1280 NEXT N
1281 X=A(H)
1282 Y=(A(H+1)-A(H-1))/2
1283 Z=(A(H+1)+A(H-1)-2*X)/2
1284 F6(L)=-(Y/(2*Z))
1285 A6(L)=X+Y*F6(L)+Z*F6(L)^2
1286 F6(L)=F4(H)+F6(L)*(F4(H)-F4(H-1))
1290 A7(L)=A6(L)/SQR(2)
1300 FOR N=0 TO H
1310 IF A7(L)=A(N) THEN 1410
1320 IF A7(L)<A(N) THEN 1370
1330 IF A(N)<B1 THEN 1450
1340 B1=A(N)
1350 H1=N
1360 GOTO 1450
1370 IF A(N)>B2 THEN 1400
1380 B2=A(N)
1390 H2=N
1400 GOTO 1450
1410 B1,B2=A(N)
1420 H1,H2=N
1430 F7=F4(H2)
1440 GOTO 1470
1450 NEXT N
1451 X=(A7(L)-B1)/(B2-B1)
1460 F7=X*(F4(H2)-F4(H1))+F4(H1)
1470 FOR N=H TO 25
1480 IF A7(L)=A(N) THEN 1580
1490 IF A7(L)>A(N) THEN 1540
1500 IF A(N)>B3 THEN 1530
1510 B3=A(N)
1520 H3=N
1530 GOTO 1620
1540 IF A(N)<=B4 THEN 1570
1550 B4=A(N)
1560 H4=N
1570 GOTO 1620
1580 B3,B4=A(N)
1590 H3,H4=N
1600 F8=F4(H3)
1610 GOTO 1640
```

```
1620 NEXT N
1621 X=(A7(L)-B4)/(B3-B4)
1630 F8=-(X*(F4(H4)-F4(H3)))+F4(H4)
1640 Q(L)=F6(L)/(F8-F7)
1641 PRINT "MODE ":L:
1642 PRINT "CENTER FREQ IS ":F6(L);" AND AMP IS ":A6(L)*A5
1643 PRINT "Q IS ":Q(L)
1650 IF B1=0 THEN 1655
1651 IF B4=0 THEN 1655
1652 IF B2=50 THEN 1655
1653 IF B3=50 THEN 1655
1654 GOTO 1658
1655 PRINT "3dB POINT NOT FOUND. REPEATING MEASUREMENT. MODE ":L
1656 Q(L)=2*Q(L)
1657 GOTO 771
1658 IF A6(L)>.3 THEN 1664
1659 A8(L)=2*A8(L)
1660 A6(L)=2*A6(L)
1661 IF A8(L)<A1 THEN 1658
1662 A8(L)=A1
1663 GOTO 1671
1664 IF A6(L)<.95 THEN 1671
1665 A8(L)=A8(L)/2
1666 A6(L)=A6(L)/2
1667 GOTO 1664
1671 CLEAR
1672 PRINT USING 1673
1673 IMAGE 5/
1680 NEXT L
1690 CLEAR @ GCLEAR
1691 DISP "I am working on time constant"
1699 ' From 1700 to 1740 the largest Time Constant is found
1700 FOR L=1 TO M
1701 T(L)=Q(L)/(PI*F6(L))
1702 NEXT L
1705 T=T(1)
1710 FOR L=2 TO M
1711 IF T>T(L) THEN 1720
1712 T=T(L)
1720 NEXT L
1750 BEEP @ CLEAR
1755 PRINT "TIME CONST >= ":T*1000
1760 DISP "Set and enter new time constant (in milli-sec)"
1770 DISP "MUST BE GREATER THAN ";T;" sec"
1780 INPUT Y
1781 T1=Y
1782 IF 25*(T1*12+200)>153000 THEN 1783 ELSE 1785
1783 D9=INT(25*(T1*12+200)/51000)
1784 GOTO 1786
1785 D9=3
1786 CLEAR
1791 PRINT "# OF RAVINES IS ":D9
1792 PRINT "NEW TIME CONST IS ":T1
1793 PRINT USING 1794
1794 IMAGE 4/
1795 ! MEASURE
1796 ' MEASURE
1797 ' MEASURE
1798 ' MEASURE
1799 DISP "I am working on standard dev. # of pts. & variance "
```

```
1800 ! From 1800 to 1924 is the calc of the noise, st. dev., and the number of p
ts. used.
1801 G.W=0
1802 F=(F6(2)-F6(1))/4+F6(1)
1803 F4$=VAL$(F)
1804 OUTPUT 717 ;H2$.F4$.H1$
1805 WAIT T1*12+100
1806 OUTPUT 709 ;"VT1"
1807 WAIT 1000
1808 FOR N=1 TO 100
1809 ENTER 709 ; A(N)
1810 W=W+A(N)
1811 NEXT N
1812 W=W/100
1813 FOR N=1 TO 100
1814 S=(A(N)-W)^2
1815 G=G+S
1816 NEXT N
1817 G=A5*SQR(G/99)
1818 W=W*A5
1819 PRINT "The mean is ":W
1820 PRINT "The standard dev is ":G
1821 PRINT USING 1822
1822 IMAGE 4/
1825 FOR L=1 TO M
1830 I(L)=2*A6(L)*A5/(3.3*G)
1835 PRINT "NO. OF POINTS FOR MODE ";L:" IS ":I(L)
1840 IF I(L)<100 THEN 1850
1845 I(L)=100
1850 IF I(L)>50 THEN 1860
1855 I(L)=50
1860 I(L)=IP(I(L))
1861 I(L)=24
1864 PRINT "NO. CHOSEN IS ":I(L)
1865 PRINT
1866 NEXT L
1867 CLEAR @ BEEP
1880 PRINT USING 1881
1881 IMAGE 4/
1885 PRINTER IS 701,132
1887 DIM F$[20]
1888 F$="C-G RAVINE"
1889 GOTO 8999
1890 PRINT USING 1891 ; "TIME","TEMP","PRES","M #"."C. FREQ","AMP."."Q","SNR"."D
-AMP"."# PT",F$
1891 IMAGE 4A.5X.4A.6X.5A.4X.3A.6X.7A.9X.4A.14X,1A.9X.3A.5X.5A.4X.4A.6X,10A
1892 PRINT USING 1893 ; "(SEC)"."( K )"."(HZ)"."(Vrms)"."(mV)"
1893 IMAGE 5A.4X.5A.25X,4A,10X.6A.30X.4A./
1895 CLEAR
1896 ! From 1901 to END is the calculation for measure including center freq and
 Q and track
1897 Q7,Q8=1
1901 ON ERROR GOTO 6000 @ T9=0
1902 FOR L=1 TO M
1903 DISP "I AM IN MEASURE FOR MODE ":L
1906 F1=F6(L)-F6(L)/Q(L)
1907 F2=F6(L)+F6(L)/Q(L)
1908 U(L)=(F2-F1)/I(L)
1909 V(L)=(F2-F1)/2
1910 H=0 @ Q9=F6(L)
```

```
1921 A$=VAL$(A8(L))
1922 OUTPUT 717 ;A2$,A$,A3$
1923 WAIT 200
1924 ENTER 722 ; T6(L)
1925 IF L=1 THEN 1929 ELSE GOTO 7000
1926 GOTO 2650
1929 FOR Y9=0 TO I(L)
1930 X8(Y9)=F6(L)+U(L)*Y9-V(L)
1931 F4$=VAL$(X8(Y9))
1932 H1$="HZ"
1933 H2$="FR"
1934 OUTPUT 717 ;H2$,F4$,H1$
1935 WAIT 12*T1+100
1936 OUTPUT 709 ;"VT3"
1937 ENTER 709 ; X7(Y9)
1938 NEXT Y9
1939 ENTER 722 ; T5(L)
1940 FOR N=0 TO I(L)
1941 F4(N)=X8(N)
1942 A(N)=X7(N)
1943 NEXT N
1973 FOR N=1 TO I(L)-1
1974 IF A(N)<A(H) THEN 1978
1975 IF A(N)=A(H) THEN 1976 ELSE 1977
1976 PRINT A(N)
1977 H=N
1978 NEXT N
1979 X=A(H)
1980 Y=(A(H+1)-A(H-1))/2
1990 Z=(A(H+1)+A(H-1)-2*X)/2
2000 F6(L)=-(Y/(2*Z))
2010 A6(L)=X+Y*F6(L)+Z*F6(L)^2
2020 F6(L)=F4(H)+F6(L)*(F4(H)-F4(H-1))
2030 B1,B4,H1,H2,H3,H4=0
2040 B2,B3=50 @ PRINTER IS 701,132
2290 A7(L)=A6(L)/SQR(2)
2300 FOR N=0 TO H
2310 IF A7(L)=A(N) THEN 2410
2320 IF A7(L)<A(N) THEN 2370
2330 IF A(N)<B1 THEN 2450
2340 B1=A(N)
2350 H1=N
2360 GOTO 2450
2370 IF A(N)>B2 THEN 2400
2380 B2=A(N)
2390 H2=N
2400 GOTO 2450
2410 B1,B2=A(N)
2420 H1,H2=N
2430 F7=F4(H2)
2440 GOTO 2470
2450 NEXT N
2451 IF B2=50 THEN PRINT "COULD NOT FIND 3dB DOWN PARAMETER" @ GOTO 6020
2452 IF B1=0 THEN PRINT "COULD NOT FIND 3dB DOWN PARAMETER" @ GOTO 6020
2459 X=(A7(L)-B1)/(B2-B1)
2460 F7=X*(F4(H2)-F4(H1))+F4(H1)
2470 FOR N=H TO I(L)
2480 IF A7(L)=A(N) THEN 2580
2490 IF A7(L)>A(N) THEN 2540
2500 IF A(N)>B3 THEN 2530
```

```
2510 B3=A(N)
2520 H3=N
2530 GOTO 2620
2540 IF A(N)<=B4 THEN 2570
2550 B4=A(N)
2560 H4=N
2570 GOTO 2620
2580 B3,B4=A(N)
2590 H3,H4=N
2600 F8=F4(H3)
2610 GOTO 2631
2620 NEXT N
2621 IF B3=50 THEN PRINT "COULD NOT FIND 3dB DOWN PARAMETER" @ GOTO 6020
2622 IF B4=0 THEN PRINT "COULD NOT FIND 3dB DOWN PARAMETER" @ GOTO 6020
2629 X=(A7(L)-B4)/(B3-B4)
2630 F8=-(X*(F4(H4)-F4(H3)))+F4(H4)
2631 Q(L)=F6(L)/(F8-F7)
2632 FOR N=1 TO 24
2633 E6(N)=F4(N)
2634 E7(N)=A(N)
2635 NEXT N
2641 PRINTER IS 701,132
2642 CLEAR
2643 IF L=1 THEN 2644 ELSE GOTO 3420
2644 I5=I5+1
2645 Q9=F6(1)/Q9
2646 FOR N=2 TO M
2647 F6(N)=Q9*F6(N)*Q8
2648 NEXT N
2649 GOTO 3420
2650 FOR N=0 TO M-1
2651 IF L=M-N THEN X1=M-N-1 ELSE 2653
2652 IF X1=0 THEN X1=M
2653 NEXT N
2660 FOR N=1 TO 24
2661 E1(N)=E6(N)
2662 E2(N)=E7(N)
2663 NEXT N
2664 E3=A6(X1)
2665 E4=F6(X1)
2666 E5=Q(X1)
2677 !
2678 !
2679 ! VARY Q
2680 FOR B=1 TO D9
2685 FOR K=1 TO 3
2689 DISP "I AM IN RAVINE FOR Q OF MODE ";X1;" SHOT ";B;".";K
2690 J(1)=E5
2700 J(2)=1.005*E5
2710 J(3)=.995*E5
2711 R=E3
2720 E(K)=0
2730 FOR N=1 TO I(X1)
2740 C(N)=R/(J(K)*SQR((E1(N)/E4-E4/E1(N))^2+(1/J(K))^2))
2750 D=(E2(N)-C(N))^2
2760 E(K)=E(K)+D
2770 NEXT N
2775 CLEAR
2780 NEXT K
2813 V1(X1)=-((E(2)-E(3))/(2*(E(2)+E(3)-2*E(1))))
```

```
2814 E5=J(1)+V1(X1)*.005*J(1)
2876 !
2877 !
2878 !
2879 ! VARY AMP
2880 CLEAR
2881 FOR K=1 TO 3
2889 DISP "I AM IN RAVINE FOR AMPLITUDE OF MODE ";X1;" SHOT ";B;".";K
2890 J(1)=E3
2900 J(2)=1.002*E3
2910 J(3)=.998*E3
2920 E(K)=0
2930 FOR N=1 TO I(X1)
2940 C(N)=J(K)/(E5*SQR((E1(N)/E4-E4/E1(N))^2+(1/E5)^2))
2950 D=(E2(N)-C(N))^2
2960 E(K)=E(K)+D
2970 NEXT N
2975 CLEAR
2980 NEXT K
3020 V1(X1)=-((E(2)-E(3))/(2*(E(2)+E(3)-2*E(1))))
3030 E3=J(1)+V1(X1)*.002*J(1)
3176 !
3177 !
3178 !
3179 ! VARY FREQ
3180 CLEAR
3181 FOR K=1 TO 3
3189 DISP "I AM IN RAVINE FOR FREQUENCY OF MODE ";X1;" SHOT ";B;".";K
3190 J(1)=E4
3200 J(2)=.005*E4/E5+E4
3210 J(3)=-(.005*E4/E5)+E4
3211 R=E3
3220 E(K)=0
3230 FOR N=1 TO I(X1)
3240 C(N)=R/(E5*SQR((E1(N)/J(K)-J(K)/E1(N))^2+(1/E5)^2))
3250 D=(E2(N)-C(N))^2
3260 E(K)=E(K)+D
3270 NEXT N
3275 CLEAR
3280 NEXT K
3305 V1(X1)=-((E(2)-E(3))/(2*(E(2)+E(3)-2*E(1))))
3306 E4=J(1)+V1(X1)*.005*J(1)/E5
3307 NEXT B
3308 !
3309 !
3310 !
3311 ! LAST SHOT RAVINE #
3312 CLEAR
3314 DISP "I AM IN LAST SHOT R"
3316 J1=E3
3318 E=0
3319 FOR N=1 TO I(X1)
3320 C(N)=J1/(E5*SQR((E1(N)/E4-E4/E1(N))^2+(1/E5)^2))
3321 D=(E2(N)-C(N))^2
3322 E=E+D
3323 NEXT N
3326 J1=J1*A5
3327 Y=J1/G
3328 DIM G$[132]
3350 ASSIGN# 1 TO Z$
```

```
3360 T4=TIME
3371 T7=(T5(X1)+T6(X1))/2
3380 P5=-(.00765*((T7-7)/2)^2)+.07055*(T7-7)/2+1.6481
3381 A6(X1)=E3
3382 F6(X1)=E4
3383 Q(X1)=E5
3390 PRINT# 1,I5-1 : T4,P5,T7,X1,E4,J1,E5,Y,A8(X1),I5-1,E
3391 ASSIGN# 1 TO *
3392 G$="5D,2X,3D.3D,2X,D.3DE,2X,2D,4X,3DC3D.5D,4X,D.4DE,6X,3D.4D,3X,3DC3D,3X,4D
,5X,3D,6X,D.4DE"
3393 PRINT USING G$ : T4,P5,T7,X1,E4,J1,E5,Y,A8(X1),I5-1,E
3403 IF X1=L THEN 4981
3405 I5=I5+1
3406 IF Y9<24 THEN OFF TIMER# 1 @ GOTO 3407 ELSE 3415
3407 FOR Y8=Y9 TO I(L)
3408 H2$="FR" @ H1$="HZ"
3409 F4$=VAL$(X8(Y8))
3410 OUTPUT 717 ;H2$,F4$,H1$
3411 WAIT 12*T1+100
3412 OUTPUT 709 ;"VT3"
3413 ENTER 709 ; A(Y8)
3414 NEXT Y8
3415 GOTO 1939
3420 F4$=VAL$(F6(L))
3421 IF L>1 THEN 3422 ELSE 3430
3422 Q9=F6(L)/Q9
3423 IF L=M THEN 3427
3424 FOR N=L+1 TO M
3425 F6(N)=Q9*F6(N)*Q8
3426 NEXT N
3427 FOR N=1 TO L-1
3428 F6(N)=Q9*F6(N)*Q8
3429 NEXT N
3430 A$=VAL$(A8(L))
3431 Q7,Q8=1
3440 OUTPUT 717 ;A2$,A$,A3$
3450 WAIT 200
3460 OUTPUT 717 ;H2$,F4$,H1$
3470 WAIT T1*16+100
3480 OUTPUT 709 ;"VT3"
3490 ENTER 709 ; C8(L)
3491 IF T9=M THEN 3492 ELSE 4978
3492 T9=M+1
3493 X1=L
3494 GOTO 2660
4978 T9=L+1
4980 CLEAR
4981 NEXT L
4982 PRINTER IS 701,132
4983 PRINT USING 4984
4984 IMAGE /
4995 !
4996 !
4997 !
4998 ! TRACK
5000 T9=0
5010 FOR L=1 TO M
5011 DISP "I AM TRACKING MODE ";L
5020 F4$=VAL$(F6(L))
5030 A$=VAL$(A8(L))
```

```
5040 OUTPUT 717 ;A2$.A$.A3$
5041 WAIT 200
5050 OUTPUT 717 ;H2$.F4$.H1$
5060 WAIT T1*16+2000
5061 OUTPUT 709 ;"VT3"
5070 ENTER 709 : A9
5080 IF A9<=.9*C8(L) THEN 5110
5090 IF A9>=1.1*C8(L) THEN 5110
5100 GOTO 5120
5110 T9=L
5120 IF A9>.3 THEN 5210
5130 A8(L)=2*A8(L)
5140 A9=2*A9
5150 IF A8(L)<A1 THEN 5120
5160 A8(L)=A1
5170 GOTO 5250
5210 IF A9<.95 THEN 5245
5220 A8(L)=A8(L)/2
5230 A9=A9/2
5240 GOTO 5210
5245 CLEAR
5250 NEXT L
5260 ENTER 722 : T8
5270 IF ABS(T8-T7)>=.2 THEN 1901
5290 IF T9<1 THEN 5010
5301 T4=TIME
5310 PRINT "GONE TO MEASURE DUE TO AMPLITUDE AT TIME ";T4;"  MODE ";T9
5320 GOTO 1901
6000 ! ERROR ROUTINE
6001 OFF TIMER# 1
6010 PRINT "Error detected, mode ":L:" ERRL = ":ERRL;" ERRN = ":ERRN
6020 H=0
6030 FOR N=1 TO I(L)-1
6040 IF A(N)<A(H) THEN 6080
6050 IF A(N)=A(H) THEN 6060 ELSE 6070
6060 PRINT A(N)
6070 H=N
6080 NEXT N
6090 IF Q8=1 THEN 6095 ELSE 6093
6093 Q7=Q8
6095 Q8=F4(H)
6100 Q8=Q8/F6(L)
6110 Q8=Q8*Q7
6120 F6(L)=F4(H)
6121 F4$=VAL$(F6(L))
6122 A$=VAL$(A8(L))
6123 OUTPUT 717 ;A2$.A$.A3$
6124 WAIT 200
6125 OUTPUT 717 :H2$,F4$,H1$
6126 WAIT T1*16+2000
6127 OUTPUT 709 ;"VT3"
6128 ENTER 709 ; A9
6129 IF A9>.3 THEN 6135
6130 A8(L)=2*A8(L)
6131 A9=2*A9
6132 IF A8(L)<A1 THEN 6129
6133 A8(L)=A1
6134 GOTO 6139
6135 IF A9<.95 THEN 6139
6136 A8(L)=A8(L)/2
```

```
6137 A9=A9/2
6138 GOTO 6135
6139 CLEAR
6140 OFF ERROR
6141 IF D9>3 THEN 6199
6142 CLEAR @ DISP "I AM GOING THROUGH POINTS FOR MODE ":L
6143 OUTPUT 717 ;A2$.A8(L).A3$
6144 WAIT 200
6145 F1=F6(L)-F6(L)/Q(L)
6146 F2=F6(L)+F6(L)/Q(L)
6147 U(L)=(F2-F1)/I(L)
6148 V(L)=(F2-F1)/2
6149 H=0
6150 FOR N=0 TO I(L)
6151 F4(N)=F6(L)+U(L)*N-V(L)
6152 OUTPUT 717 ;H2$,F4(N).H1$
6153 WAIT 12*T1+100
6154 OUTPUT 709 :"VT3"
6155 ENTER 709 ; A(N)
6156 NEXT N
6157 FOR N=1 TO I(L)
6158 IF A(N)<A(H) THEN 6160
6159 H=N
6160 NEXT N
6161 IF H=0 THEN CLEAR @ GOTO 6090
6162 IF H=24 THEN CLEAR @ GOTO 6090
6163 X=.707*A(H)
6164 FOR N=0 TO H
6165 IF A(N)<X THEN 6168
6166 NEXT N
6167 CLEAR @ GOTO 6090
6168 FOR N=H TO 24
6169 IF A(N)<X THEN 6172
6170 NEXT N
6171 CLEAR @ GOTO 6090
6172 CLEAR
6199 ON ERROR GOTO 6000
6200 GOTO 1903
7000 FOR Y9=0 TO 25
7001 X8(Y9)=F6(L)+U(L)*Y9-V(L)
7006 NEXT Y9
7007 Y9=0
7010 F4$=VAL$(X8(Y9))
7015 OUTPUT 717 ;H2$.F4$,H1$
7020 ON TIMER# 1,12*T1+100 GOSUB 8000
7025 GOTO 1926
8000 IF Y9>=25 THEN 8025
8001 OFF TIMER# 1
8005 OUTPUT 709 ;"VT3"
8010 ENTER 709 ; X7(Y9)
8015 Y9=Y9+1
8016 H2$="FR" @ H1$="HZ"
8017 F4$=VAL$(X8(Y9))
8018 OUTPUT 717 ;H2$.F4$.H1$
8019 ON TIMER# 1,12*T1+100 GOSUB 8000
8020 IF Y9<25 THEN RETURN ELSE 8025
8025 OFF TIMER# 1
8030 RETURN
8100 IF 25*(T1*12+200)>153000 THEN 8101 ELSE 8103
8101 D9=INT(25*(T1*12+200)/51000)
```

```
8102 GOTO 8104
8103 D9=3
8104 PRINT "# OF RAVINES IS ";D9
8105 GOTO 1885
8990 CLEAR @ GCLEAR
8991 GOTO 9008
8992 DISP "ENTER THE STARTING # PT FOR DATA"
8993 INPUT Y
8994 I5=Y
8995 GOTO 13
8999 DISP "ENTER PREAMP GAIN" @ BEEP
9000 INPUT P$
9001 DISP "ENTER FSS FROM 5204" @ BEEP
9002 INPUT S$
9003 DISP "ENTER MULTIP. FROM 5204" @ BEEP
9004 INPUT M$
9005 PRINT "PREAMP= ";P$;"  FSS=";S$;"  MULTIP=";M$
9006 PRINT
9007 GOTO 1890
9008 DISP "THE END"
9009 END
```

```
1 ! ////////////////////////////////////////////////////////////
2 ! ////// "TMRCAL": THERMOMETER CALIBRATION ///////////////////
3 ! ////////////////////////////////////////////////////////////
20 ! VALID ONLY FOR:
30 !  4mmHg < P < 9mmHg
40 ! REQUIRES VOLTMETER (722)
50 ! REQUIRES BARATRON-DAU(709)
60 !
70 DIM R(150).P(150),V(150),T(150)
80 OUTPUT 709 ;"F1"
90 OUTPUT 722 ;"F1"
100 CLEAR @ BEEP 7,300 @ DISP "THERMOMETER CALIBRATION"
120 WAIT 2500
130 CLEAR @ BEEP 7,300 @ DISP "       BIAS CURRENT (uA)"
150 INPUT I
160 PRINT "THERMOMETER CALIBRATION"
170 PRINT
180 PRINT
190 PRINT "BIAS CURRENT=";I;"uA"
200 PRINT
210 PRINT " M    V(V)     T(K)      R(KOHM)"
220 ! CREATE DATA TAPE
230 CLEAR @ BEEP @ DISP "STORE DATA ON TAPE (Y/N)"
250 INPUT R$
255 X6=1
260 IF R$="N" THEN X6=0 @ GOTO 360
270 CLEAR @ BEEP 7.300 @ DISP "FILE NAME (<=6 CHAR.)"
280 INPUT F$
290 DISP
300 DISP
310 DISP "CREATE A NEW DATA FILE (Y/N)"
320 INPUT R$
330 IF R$="N" THEN 350
340 CREATE F$.150,40
350 ASSIGN# 1 TO F$
360 CLEAR @ BEEP 7,300 @ DISP "FIRST DATA PT.#"
370 INPUT A
380 FOR M=A TO A+149
390 ENTER 722 ; P(M)
400 ENTER 709 ; V(M)
401 IF M>=2 THEN 402 ELSE GOTO 410
402 IF ABS(P(M)-P(M-1))<.1 THEN 448
410 R(M)=V(M)*.001/(I*.000001)
420 T(M)=-(.00765*((P(M)-7)/2)^2)+.07055*(P(M)-7)/2+1.6481
430 PRINT USING 435 ; M,V(M),T(M),R(M)
435 IMAGE 3D.1X.1DZ.4D.1X.1DZ.5D.2X.3DZ.5D
440 IF X6#0 THEN PRINT# 1,M ; M,P(M),V(M),T(M),R(M)
447 GOTO 450
448 M=M-1
450 NEXT M
460 ASSIGN# 1 TO *
470 END
```

```
1 ! ////////////////////////////////////////////////////////////
2 ! ///////"COOLDN": MONITORS THERMOM ON COOLDOWN //////////////
10 ! "Cool-down" thermometer
20 ! program.  Requires 5316
30 ! counter(#720) and 3438A
40 ! multimeter(#723).
50 !
60 !
100 ! Set-up
110 OUTPUT 720 ;"INWA1"
120 DISP "Enter mode number"
130 INPUT N
140 PRINT " Time    Temp(K)   R(ohms)"
200 ! Data
210 !
220 TRIGGER 720
230 TRIGGER 723
240 ENTER 723 ; R
250 ENTER 720 ; F
260 T=.0000248*(F*F)/(N*N)
265 T1=TIME
270 PRINT USING 280 ; T1,T,R
280 IMAGE X,5D,2X,DDD.DD,2X,DDDDD
290 WAIT 300000
300 GOTO 220
400 END
```

```
1 ! ////////////////////////////////////////////////////////////
2 ! /////// "P vs t" : PLOTS PRESS REGULATOR TRENDS ////////////
10 DIM P(100)
12 MAT P=(6.6)
15 PRINT "   N       TIME    P(mmHg)"
16 PRINT USING 17
17 IMAGE /
20 FOR N=1 TO 100
25 GCLEAR
30 TRIGGER 709
40 ENTER 709 : P(N)
50 PRINT USING 60 : N.TIME.P(N)
60 IMAGE 2X.3D.5X,5D.4X.D.DDDD
70 GOSUB 300
80 WAIT 240000
90 NEXT N
300 SCALE 1.100.6.75.7.15
305 XAXIS 6.75.10
306 YAXIS 1..05
310 FOR I=1 TO 100
315 DRAW I.P(I)
325 NEXT I
335 RETURN
400 END
```

APPENDIX B

DATA ANALYSIS COMPUTER PROGRAMS

1) REDUCE..... Uses raw data to calculate upper, lower and reciprocity temperature amplitude oscillations; provides the capability of entering raw data by magnetic tape, by hand or a combination of both.

2) QUICK...... Like REDUCE, except no lower limits are calculated and raw data is entered only by magnetic tape; therefore, a much faster output of reduced data is obtained (Appendix D).

3) KERRY...... Extracts and prints raw data from magnetic tape when a hard copy of this data is required.

4) GETDAT..... A short program used to retrieve and print thermometer calibration data from a magnetic tape.

5) SPLINE..... Incorporates the basic program suggested in reference 38 to compute absolute helium temperature from a given pressure.

```
1 ! ///////////// "REDUCE": He DATA REDUCTION .... WITH T/T
2 ! ///////////// THIS PROGRAM DOES NOT HAVE CUBIC SPLINE TEMPS
3 ! ////////////// THIS PROGRAM DOES NOT HAVE E/E INPUT VOLTAGE CORRECTION
4 ! ////////////// THIS PROGRAM DOES NOT AUTOMATICALLY TAKE CARE OF THERMO. CONST
ANT
5 ! ////////////// TEMPERATURE SWINGS ARE REFERENCED TO THERMAL DRIVE
10 OPTION BASE 1
20 DIM A(5),M(5).Y(5).X(150.2)
30 DIM F(40).M9(40).Q(40).T(40),V0(40).V1(40),Y2(40)
40 ! He DATA REDUCTIN PROGRAM
50 X4=1
70 CLEAR @ BEEP 7,300
80 IF X4=1 THEN 100
90 RETURN
100 X4=0
110 DISP "THIS PROGRAM WILL OBTAIN UPPER  AND LOWER THERMAL LIMITS FROM He DATA.
"
120 DISP @ DISP "RECIPROCITY CALCULATIONS ARE    ALSO PERFORMED."
122 WAIT 7000
124 GOSUB 70
130 DISP "DATA CAN BE ENTERED BY KEYBOARD  AND/OR TAPE."
132 DISP @ DISP "THERMOM. CALIB.,T/T,E/E,T/E DATA WILL BE ENTERED:"
134 DISP @ DISP
135 DISP "    (A) BY TAPE                         (B) BY KEYBOARD                     (C)
 KEYBOARD & TAPE"
136 INPUT L$
137 IF L$="A" OR L$="B" OR L$="C" THEN GOTO 138 ELSE BEEP 70.370 @ GOTO 135
138 IF L$="A" OR L$="C" THEN BEEP @ DISP "INSERT DATA TAPE FOR LATER USE." @ WAI
T 3500
139 GOSUB 70
140 DISP "THERMOMETER CALIBR. AND ALL He  DATA SHOULD BE ON THE SAME TAPE. BUT I
TS NOT REQ'D."
142 DISP
150 DISP "CHANGING RESONATOR DEPENDENT    DATA IS AN AVAILABLE OPTION IN  THIS P
ROGRAM."
155 WAIT 8000
160 GOSUB 70
170 DISP "PART 1:FINDING dR/dT FROM THERMOM. CALIB. DATA."
175 WAIT 4000
180 BEEP @ DISP
190 DISP "PRINT TEMP AND RESIST VALUES ON INPUT.(Y/N)"
200 INPUT R$
210 X6=0 @ IF R$="N" THEN 232
220 IF R$#"Y" THEN 190
230 X6=1
232 IF L$="A" THEN 420
234 IF L$="B" THEN 280
236 CLEAR
240 BEEP 7.300 @ DISP "TEMP vs RESIST DATA FROM KEYBD  OR TAPE. (K/T)"
250 INPUT R$
260 IF R$="T" THEN 420
270 IF R$#"K" THEN BEEP 70,370 @ GOTO 240
280 IF X6#1 THEN 320
290 PRINT
300 PRINT TAB(4);"N";TAB(13);"T(N)":TAB(27):"R(N)"
310 PRINT TAB(13);"(K)";TAB(26);"(KOHM)" @ PRINT
315 GOSUB 70
320 DISP "HOW MANY T&R DATA PAIRS. (2-150)"
330 INPUT N@ DISP
```

```
340 IF N>150 OR N<=1 THEN BEEP 70,370 @ DISP "INVALID NUMBER OF T&R PAIRS" @ GOS
UB 320
342 GOSUB 70
350 FOR I=1 TO N
352 FOR I=1 TO N
360 DISP "T(";I;"),R(";I;")=";
370 INPUT X(I,1),X(I,2)
380 IF X6=1 THEN PRINT USING 390 ; I,X(I,1),X(I,2)
390 IMAGE 4D,3X,3DZ.4D,2X,6DZ.4D
400 NEXT I
402 BEEP @ WAIT 300 @ BEEP
410 DISP "DATA ENTERED" @ WAIT 2000 @ GOTO 610
420 BEEP @ CLEAR @ DISP "RESIST. CALIB. DATA FILE NAME";
430 INPUT F$
440 ASSIGN# 1 TO F$
450 BEEP @ DISP "FIRST ";F$;" DATA PT.#"
460 INPUT K1
470 BEEP @ DISP "LAST ";F$;" DATA PT.#"
480 INPUT K2
490 FOR N=K1 TO K2
500 READ# 1 ; N,P,V,X(N,1),X(N,2)
510 NEXT N
520 ASSIGN# 1 TO *
530 IF X6<>1 THEN 770 ELSE T=1
540 PRINT TAB(4);"N";TAB(13);"T(N)";TAB(27);"R(N)"
550 PRINT TAB(13);"(K)";TAB(26);"(KOHM)" @ PRINT
560 FOR I=K1 TO K2
570 PRINT USING 390 ; I,X(I,1),X(I,2)
580 NEXT I
590 PRINT
600 IF T=1 THEN 770
610 ! CLEAR @ BEEP @ DISP "STORE YOUR!DATA.  (Y/N)"
620 ! INPUT R$
630 ! IF R$="N" THEN 770
632 ! IF R$#"Y" THEN BEEP 70,370 @ GOTO 610
640 ! DISP @ BEEP @ DISP "FILE NAME...<7 CHARACTERS"
650 ! INPUT F$
660 ! DISP @ BEEP @ DISP "CREATE ";F$;" FILE.    (Y/N)"
670 ! INPUT R$
680 ! IF R$="N" THEN 700
682 ! IF R$#"Y" THEN 660
690 ! CREATE F$,150,24
700 ! ASSIGN# 1 TO F$
710 ! DISP @ BEEP @ DISP "FIRST ";F$;" DATA PT.#"
720 ! INPUT K1
730 ! FOR M=K1 TO K2
740 ! PRINT# 1 ; M,T,R
750 ! NEXT M
760 ! ASSIGN# 1 TO *
770 ! SETTING UP dR/dT
800 Y(1),Y(3)=INF @ Y(2),Y(4)=-INF @ A(1),A(2),A(3),A(4),A(5)=0
805 IF L$="B" OR R$="K" THEN K1=1 @ K2=N
810 FOR I1=K1 TO K2
820 IF Y(2)<X(I1,1) THEN Y(2)=X(I1,1)
830 IF Y(1)>X(I1,1) THEN Y(1)=X(I1,1)
840 IF Y(4)<X(I1,2) THEN Y(4)=X(I1,2)
850 IF Y(3)>X(I1,2) THEN Y(3)=X(I1,2)
860 A(1)=A(1)+X(I1,1) @ A(2)=A(2)+X(I1,1)*X(I1,1) @ A(3)=A(3)+X(I1,2)
870 A(4)=A(4)+X(I1,2)*X(I1,2) @ A(5)=A(5)+X(I1,1)*X(I1,2)
880 NEXT I1
```

```
985 N=K2-K1+1
890 M(1)=A(1)/N @ M(2)=(A(2)-A(1)*A(1)/N)/(N-1) @ M(3)=A(3)/N
900 M(4)=(A(4)-A(3)*A(3)/N)/(N-1) @ M(5)=(A(5)-A(1)*A(3)/N)/(A(2)-A(1)*A(1)/N)
910 R5=M(3)-M(1)*M(5)
920 GOSUB 70
947 ! EXPONENTIAL REGRESSION BEGINS
950 PRINT @ PRINT
960 IF Y(1)<=0 OR Y(2)<=0 THEN CLEAR @ BEEP 70.370 @ DISP "CAN'T TAKE LOG OF A N
EG.  TEMP." @ GOTO 970
965 GOTO 990
970 DISP
980 DISP "CHECK RESIST. CALIB. DATA AND    ENTER 'Y'  IF YOU WANT TO ENTER NEW D
ATA."
982 INPUT S$
984 IF S$="Y" THEN 315
986 IF S$#"Y" THEN 980
990 Q1=A(3) @ Q2=A(4) @ Q3=A(5) @ A(3).A(4).A(5)=0
1000 FOR I=K1 TO K2
1010 T1=LOG(X(I.1)) @ T2=LOG(X(I.2)) @ A(3)=A(3)+T2 @ A(4)=A(4)+T2*T2
1020 A(5)=A(5)+X(I.1)*T2
1030 NEXT I
1035 N=K2-K1+1
1040 C=M(5) @ D=M(3) @ E=M(4) @ F=R5 @ M(3)=A(3)/N
1050 M(4)=(A(4)-A(3)^2/N)/(N-1) @ M(5)=(A(5)-A(1)*A(3)/N)/(A(2)-A(1)*A(1)/N) @ R
5=M(3)-M(1)*M(5)
1060 S=M(5)*(A(5)-A(1)*A(3)/N)
1070 R2=S/(A(4)-A(3)*A(3)/N)
1080 PRINT USING 1090 ; R2
1090 IMAGE "CORRELATION COEFF.=".2DZ.8D.2/
1100 PRINT USING 1110 ; EXP(R5).M(5)
1110 IMAGE "RHAT=".5DZ.4D."EXP(".4DZ.4D."T)"
1130 DISP "CARE TO ESTIMATE A RESISTANCE.    (Y/N)"
1140 INPUT R$
1150 IF R$="N" THEN 1390
1155 IF R$#"Y" THEN 1130
1160 PRINT @ PRINT
1162 DISP @ BEEP
1170 DISP "WANT ESTIMATE AND RESIDUALS FOR ALL PREVIOUSLY ENTERED DATA.     (Y/N
)"
1180 INPUT R$
1190 IF R$="N" THEN 1290
1192 IF R$#"Y" THEN BEEP @ GOTO 1170
1200 PRINT "  T(I)    R(I)    RHAT    RESID"
1210 PRINT
1220 FOR I=K1 TO K2
1230 Y=FNV(X(I.1))
1240 PRINT USING "2DZ.3D.4DZ.2D.4DZ.2D.4DZ.3D" : X(I.1).X(I.2),Y.X(I.2)-Y
1250 NEXT I
1252 G8=0 @ PRINT
1260 CLEAR @ BEEP @ DISP "...EST. FOR ANY OTHER TEMP.(Y/N)"
1270 INPUT R$
1280 IF R$="N" THEN 1390
1281 IF R$#"Y" THEN BEEP 70.370 @ GOTO 1260
1282 IF G8=1 THEN 1310
1290 PRINT "    T(I)          RHAT"
1310 CLEAR @ BEEP @ DISP "YOU WANT RESIST. AT TEMP.="
1320 INPUT T
1330 Y=FNV(T)
1340 PRINT USING "2DZ.5D.5X.4DZ.5D" : T.Y
1342 G8=1
```

```
1350 GOTO 1260
1360 DEF FNV(X)
1370 FNV=EXP(R5+M(5)*X)
1380 FN END
1390 GOSUB 70
1400 DISP "OBTAINING EXPRESSION FOR dR/dT"
1410 WAIT 1500
1420 Y=EXP(R5)*M(5) @ PRINT @ PRINT
1430 PRINT USING 1440 ; Y,M(5)
1440 IMAGE "dR/dT=",5DZ.3D,"EXP(",4DZ.4D,"T)"
1450 GOSUB 70
1460 DISP "PART 2: UPPER & LOWER LIMITS      FROM T/T DATA."
1470 ! THE LOWER LIMIT PART
1475 DISP
1480 DISP "ENTER I(BIAS) USED IN THERMOM.     CALIB. (uA)"
1490 INPUT B2
1491 IF L$="A" THEN 1790
1492 IF L$="B" THEN 1540
1493 GOSUB 70
1500 DISP "TH/TH DATA FROM KEYBD. OR TAPE.(K/T)"
1510 INPUT R$
1520 IF R$="T" THEN 1790
1530 IF R$#"K" THEN 1500
1540 GOSUB 70
1550 DISP "FIRST T/T DATA PT.#"
1560 INPUT K3
1570 BEEP @ DISP "LAST T/T DATA PT.#"
1580 INPUT K4
1590 GOSUB 70
1600 X6,Z,X3=0
1605 DISP "WILL YOU ENTER TEMP OR PRESS      VALUES.  (T/P)"
1607 INPUT R$
1610 FOR I5=K3 TO K4
1620 CLEAR @ BEEP @ DISP "F(";I5;"),Vout(";I5;"),Q(";I5;"),  Vi(";I5;")="
1630 INPUT F(I5),VO(I5),Q(I5),V1(I5)
1640 IF X6=1 THEN 1690
1650 IF Z=1 THEN 1760
1680 IF R$="T" THEN Z=1 @ GOTO 1760 ELSE X6=1
1690 GOSUB 1710
1700 GOTO 1750
1701 DISP "PART 1:FINDING dR/dT FROM THERMOM. CALIB. DATA."
1710 BEEP @ DISP @ DISP "ENTER PRESSURE"
1720 INPUT P
1730 T=-(.00765*((P-7)/2)^2)+.07055*(P-7)/2+1.6481
1732 Z1=1
1740 RETURN
1750 T(I5)=T @ GOTO 1920
1760 DISP "T(";I5;")="
1770 INPUT T(I5)
1780 Z=1 @ GOTO 1920
1790 GOSUB 70
1800 DISP "T/T DATA FILE NAME."
1810 INPUT F$
1830 DISP "T/T....FIRST ";F$;" DATA PT.#"
1840 INPUT K3
1850 DISP "T/T....LAST ";F$;" DATA PT.#"
1860 INPUT K4
1862 X3=0
1865 ASSIGN# 1 TO F$
1868 I5=1
```

```
1870 FOR H5=K3 TO K4
1880 READ# 1.H5 ; T1.T.P.M.F.V0,Q.S.V1.H5,C
1890 T(I5)=T @ V0(I5)=V0 @ V1(I5)=V1 @ Q(I5)=Q @ F(I5)=F
1920 Y2(I5)=FNU(T(I5))
1922 IF X3=1 THEN 2420
1930 ! THE UPPER LIMIT PART
1940 GOSUB 70
1950 DISP "NOTE:";
1960 DISP " (1)RESONATOR GEOMETRY IAW...                LAB BOOK P.29"
1970 DISP " (2)CONSTANTS ARE REF. TO               T= 1.65K"
1980 DISP @ DISP
1990 G1=2.0564 @ G2=56.406 @ C1=.1453 @ C2=2041 @ C3=1.867
2000 DISP "DIAM.(SQU'D)=";G1;"SQR. cm"
2010 DISP "HEATER RESIST.=";G2;"Ohms"
2020 DISP "He DENSITY=";C1;"g/cc"
2030 DISP "SPEED (U2)=";C2;"cm/S"
2040 DISP "SPEC. HEAT (Cp)=";C3;"J/(g-K)"
2050 DISP @ BEEP 7,300
2060 DISP "CHANGE ANYTHING ?? (Y/N)"
2070 INPUT R$
2080 IF R$="N" THEN 2410
2082 IF R$#"Y" THEN 2060
2090 GOSUB 70
2100 DISP "DIAMETER...(Y/N)"
2110 INPUT R$
2120 IF R$="N" THEN 2160
2122 IF R$#"Y" THEN 2100
2130 DISP "ENTER DIAMETER: (cm)"
2140 INPUT G
2150 G1=G^2
2160 BEEP @ DISP "HEATER RESIST...(Y/N)"
2170 INPUT R$
2180 IF R$="N" THEN 2220
2182 IF R$#"Y" THEN 2160
2190 DISP "ENTER HEATER RESIST: (Ohms)"
2200 INPUT G
2210 G2=G
2220 CLEAR @ BEEP @ DISP "IS THAT ALL. (Y/N)"
2230 INPUT R$
2240 IF R$="Y" THEN 2410
2242 IF R$#"N" THEN 2220
2250 CLEAR @ BEEP @ DISP "He DENSITY.... (Y/N)"
2260 INPUT R$
2270 IF R$="N" THEN 2310
2272 IF R$#"Y" THEN 2250
2280 DISP "ENTER He DENSITY: (g/cc)"
2290 INPUT C
2300 C1=C
2310 CLEAR @ BEEP @ DISP "SPEED (U2)....(Y/N)"
2320 INPUT R$
2330 IF R$="N" THEN 2370
2332 IF R$#"Y" THEN 2310
2340 DISP "ENTER SPEED: (cm/s)"
2350 INPUT C
2360 C2=C
2370 CLEAR @ BEEP @ DISP "SPEC. HEAT....(Y/N)"
2380 INPUT R$
2390 IF R$="N" THEN 2410
2392 IF R$#"Y" THEN 2370
2394 DISP "ENTER SPEC. HEAT... J/(g-K)"
```

```
2396 INPUT C
2398 C3=C
2410 X3=1
2420 I5=I5+1
2430 NEXT H5
2435 ASSIGN# 1 TO *
2440 DEF FNU(T)
2450 FNU=M(5)*EXP(R5)*1000*EXP(M(5)*T)
2460 FN END
2470 GOSUB 70
2480 DISP "PART 3: RECIPROCITY" @ DISP
2482 IF L$="A" THEN 2700
2484 IF L$="B" THEN 2520
2490 ! THE E/E PART
2492 X7,Z1=0
2494 DISP "E/E DATA FROM KEYBD. OR TAPE (K/T)"
2496 INPUT B$
2500 IF B$="T" THEN 2700
2510 IF B$#"K" THEN BEEP 70,370 @ GOTO 2494
2520 DISP @ BEEP @ DISP "FIRST  E/E DATA PT.#"
2530 INPUT K5
2540 DISP @ BEEP @ DISP "LAST  E/E DATA PT.#"
2542 INPUT K6
2544 DISP @ BEEP @ DISP "ENTER DRIVER CAPACITANCE: (pf)"
2546 INPUT G
2552 GOSUB 70
2554 DISP "WILL YOU ENTER TEMP OR PRESS VALUES. (T/P)"
2556 INPUT R$
2560 FOR I5=K5 TO K6
2570 CLEAR @ BEEP @ DISP "F(";I5;"),Vout(";I5;"),Q(";I5;"),      Vi(";I5;")="
2580 INPUT F(I5),V0(I5),Q(I5),V1(I5)
2590 IF Z1=1 THEN 2650
2630 IF R$="T" THEN 2670
2640 IF R$#"P" THEN 2554
2650 GOSUB 1710
2660 T(I5)=T @ GOTO 2690
2670 DISP "T(";I5;")="
2680 INPUT T(I5)
2690 GOTO 2800
2700 DISP @ BEEP @ DISP "E/E DATA FILE NAME"
2710 INPUT F$
2712 CLEAR @ BEEP @ DISP "CAPACITANCE SIDE A"
2714 INPUT P1
2716 BEEP @ DISP @ DISP "CAPACITANCE SIDE B"
2718 INPUT P2
2720 ASSIGN# 1 TO F$
2730 DISP @ BEEP @ DISP "E/E....FIRST ";F$;" DATA PT.#"
2740 INPUT K5
2750 DISP @ BEEP @ DISP "E/E....LAST ";F$;" DATA PT.#"
2760 INPUT K6
2762 DISP @ BEEP @ DISP "E/E...DRIVING SIDE A OR B. (A/B)"
2763 INPUT A$
2764 IF A$="A" THEN G=P1 @ U9=P2
2765 IF A$="B" THEN G=P2 @ U9=P1
2767 I5=10
2770 FOR H5=K5 TO K6
2780 READ# 1,H5 : T1,T,P,M,F,V0,Q,S,V1,H5,C
2790 F(I5)=F @ V0(I5)=V0 @ Q(I5)=Q @ V1(I5)=V1 @ T(I5)=T
2795 I5=I5+1
2800 NEXT H5
```

```
2860 ! DEVELOPING  (MA*MB)
2892 IF B$="K" OR L$="B" THEN 2910
2900 ASSIGN# 1 TO *
2910 ! DEVELOPING  MA/MB
2920 ! ENTERING T/EA & T/EB DATA
2930 X6=0
2940 GOSUB 70
2941 IF X6=0 THEN N$="A"
2942 IF X6=1 THEN N$="B"
2943 IF L$="A" THEN 3100
2944 IF L$="B" THEN 3000
2945 IF X6=1 THEN 2960
2950 DISP "T/EA DATA FROM KEYBD. OR TAPE.      (K/T)" @ DISP
2952 IF X6=0 THEN 2970
2960 DISP "T/EB DATA FROM KEYBD. OR TAPE.      (K/T)" @ DISP
2970 INPUT R$
2980 IF R$="T" THEN 3100
2990 IF R$#"K" THEN BEEP 70,370 @ GOTO 2940
3000 DISP "FIRST  T/E";N$;"  DATA PT.#"
3002 IF X6=1 THEN INPUT K9@ GOTO 3020
3010 INPUT K7
3020 BEEP @ DISP "LAST  T/E";N$;"  DATA PT.#"
3022 IF X6=1 THEN INPUT B1@ GOTO 3040
3030 INPUT K8
3040 IF X6=1 THEN 3222
3042 GOSUB 70
3050 FOR I5=K7 TO K8
3060 DISP "Vout(";I5;").Vi(";I5;")="
3070 INPUT V0(I5),V1(I5)
3080 NEXT I5
3090 GOTO 3220
3100 DISP "T/E";N$;" DATA FILE NAME"
3110 INPUT F$
3120 ASSIGN# 1 TO F$
3130 DISP @ BEEP @ DISP "T/E";N$;"....FIRST ";F$;" DATA PT.#"
3132 IF X6=1 THEN INPUT K9@ GOTO 3150
3140 INPUT K7
3150 DISP @ BEEP @ DISP "T/E";N$;"....LAST ";F$;" DATA PT.#"
3152 IF X6=1 THEN INPUT B1@ GOTO 3170
3160 INPUT K8
3170 IF X6=1 THEN 3280
3175 I5=20
3180 FOR H5=K7 TO K8
3190 READ# 1.H5 : T1.T.P.M.F.V0.Q.S.V1,H5.C
3204 V0(I5)=V0 @ V1(I5)=V1
3205 I5=I5+1
3206 NEXT H5
3210 ASSIGN# 1 TO *
3220 X6=1 @ GOTO 2940
3222 GOSUB 70
3230 FOR I5=K9 TO B1
3240 DISP "Vout(";I5;").Vi(";I5;")="
3250 INPUT V0(I5).V1(I5)
3260 NEXT I5
3270 GOTO 3330
3280 I5=30
3285 FOR H5=K9 TO B1
3290 READ# 1.H5 : T1.T.P.M.F.V0.Q.S.V1.H5.C
3300 V0(I5)=V0 @ V1(I5)=V1
3305 I5=I5+1
```

```
3310 NEXT H5
3320 ASSIGN# 1 TO *
3330 ! CALCULATIONS START HERE
3340 PRINT @ GOSUB 70
3350 DISP "NOW TO PUT IT ALL TOGETHER"
3352 U=0 @ WAIT 2500
3354 GOSUB 70
3356 J5=10 @ J6=20 @ J7=30
3360 FOR I5=1 TO K4-K3+1
3370 W=IP(F(I5)/100) ! T/T
3380 L=VO(I5)/(-(B2*.000001*Y2(I5)))
3385 V1(I5)=.0290666667+1.0488675*V1(I5)
3390 U=8*Q(I5)*(V1(I5)*.001)^2/(PI^2*G1*G2*C1*C2*C3*SQR(2)*W)
3400 ! E/E
3410 V1(J5)=.0290666667+1.0488675*V1(J5)
3412 VO(J5)=VO(J5)*(1+84/U9)
3420 RO=VO(J5)*W*PI*G1*C2*C3*C1/(V1(J5)*.001*16*F(J5)*G*.00000000001*Q(J5)*T(J5
))
3430 ! T/EA
3435 V1(J6)=.0290666667+1.0488675*V1(J6)
3438 VO(J6)=VO(J6)*(1+84/P1)
3440 R8=VO(J6)/(V1(J6)*.001)^2
3445 PRINT "V1(";J5;")=";V1(J5)
3446 PRINT "VO(";J5;")=";VO(J5)
3447 PRINT "RO=";RO
3450 ! T/EB
3455 V1(J7)=.0290666667+1.0488675*V1(J7)
3458 VO(J7)=VO(J7)*(1+84/P2)
3460 R9=VO(J7)/(V1(J7)*.001)^2
3470 B8=R8/R9
3472 H8=(V1(I5)/V1(J6))^2
3474 H9=(V1(I5)/V1(J7))^2
3475 PRINT "T/EA...Vout/(Vin)^2=";R8
3476 PRINT "T/EB...Vout/(Vin)^2=";R9
3477 PRINT "V(TA)/V(TB)=";B8
3480 M1=VO(J6)/SQR(RO*B8)
3490 M2=VO(J7)*B8/SQR(RO*B8)
3492 M1=M1*H8
3494 M2=M2*H9
3500 IF W=0 THEN U=U+1
3510 IF U=3 THEN 4044
3520 PRINT @ PRINT "       MODE ";W @ PRINT
3530 PRINT "LOWER LIMIT= ";L/.000001;"uK"
3540 PRINT "delta T(A)= ";M1/.000001;"uK"
3550 PRINT "delta T(B)= ";M2/.000001;"uK"
3560 PRINT "UPPER LIMIT= ";U/.000001;"uK"
3565 PRINT
3570 IF L<=M1 AND M1<=U AND L<=M2 AND M2<=U THEN PRINT "MODE ";W;" HAS CORRECT D
ISTRIBUTION."
3575 IF L>U THEN PRINT "MODE ";W;" HAS REVERSED LIMITS."
3580 IF M1<L OR M1>U THEN PRINT "MODE ";W;" HAS RECIPROCITY BEYOND LIMITS."
3581 PRINT "ABS. SENS.(A)=";SQR(RO*B8)
3582 PRINT "ABS. SENS.(B)=";SQR(RO*B8)/B8
3585 FOR I=1 TO 32
3590 PRINT "*";
3595 NEXT I
4042 IF U#3 THEN 4046
4044 I5=K4
4046 J5=J5+1 @ J6=J6+1 @ J7=J7+1
4050 NEXT I5
```

```
4052 IF U=3 THEN BEEP 70,370 @ DISP "NO MORE DATA."
4062 GOSUB 70
4064 FOR I=1 TO 5
4070 DISP
4080 NEXT I
4090 DISP TAB(11);"THAT'S ALL"
5000 END
```

```
1 ! ///////////////////////////////////////////////////////////////
2 ! ///////// QUICK .....He DATA REDUCTION //////////////////////
3 ! ////////// THIS PROGRAM HAS ALL CORRECTIONS AS OF 7 SEP 83
4 ! ////////////////////////////////////////////////////////////////
10 OPTION BASE 1
30 DIM F(40),G(13),Q(40),T(40),VO(40),V1(40),K(13),B(25),Z(29),D(4)
35 INTEGER I,J,K
38 U$="X"
39 ! ///////// SETTING UP (40-100) /////////
40 CLEAR @ BEEP @ DISP "DO YOU DESIRE COLUMN HEADINGS."
42 INPUT V$
44 IF V$#"Y" AND V$#"N" THEN 40
50 X4=1
70 CLEAR @ BEEP 7,300
72 IF X4=1 THEN 76
74 RETURN
76 X4=0
82 DISP "CHANGING  'ONLY'  DATA POINTS ? (Y/N)"
84 INPUT P$@ IF P$="Y" THEN 108
86 IF P$#"N" THEN CLEAR @ GOTO 82
92 CLEAR @ BEEP @ DISP "E/E AND T/E DATA WILL BE ENTERED:" @ DISP @ DISP
94 DISP "    (A) BY TAPE                         (B) BY KEYBOARD"
96 DISP "    (C) BY KEYBOARD & TAPE"
97 INPUT L$
98 IF L$="A" OR L$="B" OR L$="C" THEN GOTO 100 ELSE BEEP 70,370 @ GOTO 92
100 IF L$="A" OR L$="C" THEN CLEAR @ BEEP @ DISP "INSERT DATA TAPE." @ WAIT 4500

101 ! ///////// INPUT (102-116) /////////
102 CLEAR @ BEEP @ DISP "ENTER FOUR ARGUEMENTS"
104 DISP @ DISP @ DISP "  RUN #, FILE NAME, CAP'S  A,B"
106 INPUT R,F$,P1,P2
108 CLEAR @ BEEP @ DISP "ENTER 3 PAIR OF DATA END-POINTS (6 ARGUEMENTS) FOR:"
110 DISP @ DISP "   E/E, T/EA, T/EB"
112 INPUT K5,K6,K7,K8,K9,B1
114 DISP @ BEEP @ DISP "DRIVING SIDE A OR B ?"
116 INPUT A$
230 X6=1
904 DISP @ DISP
1930 ! ///////// SQR. AREA & RESISTANCE /////////
1990 G1=2.0564 @ G2=56.406
2410 X3=1
2720 ASSIGN# 1 TO F$
2725 ! ///////// SET CAPACITANCE /////////
2730 IF A$="A" THEN G=P1 @ U9=P2
2740 IF A$="B" THEN G=P2 @ U9=P1
2750 I5=10
2760 IF U$="Y" THEN 2770
2765 Y=0
2769 ! ///////// READ E/E DATA /////////
2770 FOR H5=K5 TO K6
2780 READ# 1,H5 ; T1,T,P,M,F,VO,Q,S,V1,H5,C
2785 CLEAR @ DISP "IN SEARCH OF...TEMPERATURE" @ GOSUB 6000
2786 Y=4
2790 F(I5)=F @ VO(I5)=VO @ Q(I5)=Q @ V1(I5)=V1 @ T(I5)=T
2795 I5=I5+1
2800 NEXT H5
2900 ASSIGN# 1 TO *
2930 X6=0
2941 IF X6=0 THEN N$="A"
```

```
2942 IF X6=1 THEN N$="B"
3120 ASSIGN# 1 TO F$
3170 IF X6=1 THEN 3280
3175 I5=20 @ Y=4
3178 ! /////// READ T/EA DATA ////////
3180 FOR H5=K7 TO K8
3190 READ# 1,H5 ; T1,T,P,M,F,V0,Q,S,V1,H5,C
3195 CLEAR @ DISP "GONE FISHIN' FOR...TEMPERATURE" @ GOSUB 6000
3204 V0(I5)=V0 @ V1(I5)=V1 @ T(I5)=T @ F(I5)=F @ Q(I5)=Q
3205 I5=I5+1
3206 NEXT H5
3210 ASSIGN# 1 TO *
3220 X6=1 @ GOTO 2941
3280 I5=30 @ Y=4
3283 ! //////// READ T/EB DATA ////////
3285 FOR H5=K9 TO B1
3290 READ# 1,H5 ; T1,T,P,M,F,V0,Q,S,V1,H5,C
3295 CLEAR @ DISP "WAIT...FINDING TEMPERATURE" @ GOSUB 6000
3300 V0(I5)=V0 @ V1(I5)=V1 @ T(I5)=T @ F(I5)=F @ Q(I5)=Q
3305 I5=I5+1
3310 NEXT H5
3320 ASSIGN# 1 TO *
3330 ! //////// SET HEADINGS (3331-3362) ////////
3331 PRINTER IS 701,132
3332 PRINT CHR$(27)&"&k2S"
3334 IF V$="N" THEN PRINT @ GOTO 3345
3340 PRINT @ GOSUB 70
3342 PRINT TAB(58);"RUN # ";R
3344 PRINT TAB(56);"DATA REDUCTION" @ PRINT @ PRINT
3345 PRINT " E/E  (";K5;" TO ";K6;") "
3346 PRINT " T/EA (";K7;" TO ";K8;")     ";"T/EB (";K9;" TO ";B1;")"
3347 IF V$="N" THEN PRINT @ GOTO 3365
3350 B$="Ua - Ub"
3353 PRINT @ PRINT USING 3354 ; "T","r","F","r","STr","STu",B$,"S(A)","S(B)","ST
u/STr",">1"
3354 IMAGE 10X,1A,11X,1A,2(10X,1A),8X,3A,9X,3A,7X,7A,2(9X,4A),8X,7A,7X,2A
3355 PRINT USING 3356 : "avg","avg","avg"
3356 IMAGE 9X,3A,20X,3A,30X,3A
3357 PRINT USING 3358 : "MODE","(K)","(K)","(Hz)","(Hz)","(uK)","(uK)","(uK)","(
V/K)","(V/K)"
3358 IMAGE 4A,5X,3A,9X,3A,2(7X,4A),6X,4A,2(8X,4A),10X,5A,8X,5A
3360 FOR I=1 TO 132
3361 PRINT "_";
3362 NEXT I
3363 IF U$="Y" THEN 3365
3364 U7=0
3365 J6=20 @ J7=30
3366 ! //////// CALCULATIONS ////////
3367 FOR J5=10 TO K6-K5+10
3370 W=IP(F(J5)/200) ! ........................ MODE
3385 V1(J6)=.0290666667+1.0488675*V1(J6)
3388 W9=0 @ GOSUB 7000
3390 U=8*Q(J6)*(V1(J6)*.001)^2/(PI^2*G1*G2*C1*SQR(2)*W) ! ...........STu(A)
3392 W9=2 @ GOSUB 7000
3400 U8=8*Q(J7)*(V1(J6)*.001)^2/(PI^2*G1*G2*C1*SQR(2)*W) ! .......... STu(B)
3410 V1(J5)=-.28676+.99319*V1(J5)
3412 V0(J5)=V0(J5)*(1+84/U9)
3415 W9=1 @ GOSUB 7000
3417 ! //////// PROD. of SENS's ////////
3420 R0=V0(J5)*W*PI*G1*C1/(V1(J5)*.001*16*F(J5)*G*.000000000001*Q(J5)*T(J5))
```

```
3438 VO(J6)=VO(J6)*(1+84/P1)
3440 R8=VO(J6)/(V1(J6)*.001)^2
3450 ! T/EB
3455 V1(J7)=.0290666667+1.0488675*V1(J7)
3458 VO(J7)=VO(J7)*(1+84/P2)
3460 R9=VO(J7)/(V1(J7)*.001)^2
3470 B8=R8/R9
3472 H8=1
3474 H9=(V1(J6)/V1(J7))^2
3480 M1=VO(J6)/SQR(RO*B8) ! .................. ST(A)
3490 M2=VO(J7)*B8/SQR(RO*B8) ! ............... ST(B)
3492 M1=M1*H8
3494 M2=M2*H9
3496 S1=SQR(RO*B8) ! ................ ABS. SENS.(A)
3498 S2=SQR(RO*B8)/B8 ! //////// ABS. SENS.(B)
3520 F1=(F(J5)+2*F(J6)+2*F(J7))/3
3530 T=(T(J5)+T(J6)+T(J7))/3
3532 C3=SQR((T(J5)^2+T(J6)^2+T(J7)^2)/3-T^2) ! ................. st. dev. TEMP
3534 S8=(U+U8)/2 ! .................. avg STu
3535 C4=SQR((F(J5)^2+(2*F(J6))^2+(2*F(J7))^2)/3-F1^2) ! ........ st. dev. FREQ
3536 IF M2<=S8 THEN H$="YES"
3537 IF M2>S8 THEN H$="NO"
3539 S9=U-U8
3540 ! //////// OUTPUT ////////
3541 PRINT USING 3550 ; W,T,C3,F1.C4.M2/.000001.S8/.000001.S9/.000001.S1.S2.S8/M
2,H$
3550 IMAGE 3D,2(5X.1D.4D).4X.4D.3D.4X.1D.3D.3(4X.4D.3D),7X.3D.2D.7X.3D.2D.7X,3D.
3D.7X,3A
4046 J6=J6+1 @ J7=J7+1
4050 NEXT J5
4052 CLEAR @ BEEP @ DISP "MORE DATA"
4054 INPUT U$@ IF U$="Y" THEN 40
4056 IF U$#"N" THEN 4052
4060 CLEAR
4064 FOR I=1 TO 5
4070 DISP
4080 NEXT I
4090 BEEP @ DISP TAB(11):"THAT'S ALL"
5000 END
5999 ! //////// CUBIC SPLINE TEMP SUBR. ////////
6000 IF Y=4 THEN 6080
6020 FOR I=1 TO 29
6030 READ Z(I)
6040 NEXT I
6050 FOR I=1 TO 25
6060 READ B(I)
6070 NEXT I
6080 P=P*1000
6110 P=LGT(P)
6120 T1=1 @ T2=4.215
6130 X=(T1+T2)/2
6140 I=0 @ J=22
6150 K=(I+J)/2
6160 IF J-I<=1 THEN 6200
6170 IF X>Z(K+4) THEN 6190
6180 J=K @ GOTO 6150
6190 I=K @ GOTO 6150
6200 FOR I=1 TO 4
6210 D(I)=B(I+J-1)
6220 NEXT I
```

```
6230 FOR K=1 TO 3
6240 FOR I=1 TO 4-K
6250 P8=X-Z(I+J+K-1)
6260 P9=Z(I+J+3)-X
6270 P3=1/(Z(I+J+3)-Z(I+J+K-1))
6280 D(I)=(P8*D(I+1)+P9*D(I))*P3
6290 NEXT I
6300 NEXT K
6310 IF ABS(D(1)-P)<.0001 THEN 6370
6320 IF D(1)>P THEN 6350
6330 T1=X
6340 GOTO 6130
6350 T2=X
6360 GOTO 6130
6370 T=X
6380 RETURN
6390 DATA 1.1.1.1
6400 DATA 1.15105499,1.2876575.1.43202085,1.59832713.1.74054982.1.89959361.2.101
7899
6410 DATA 2.17601406.2.18321995.2.28846654,2.57937753.2.74048335.2.88959932.3.04
057357
6420 DATA 3.18965645.3.34056636.3.47966198.3.63056679.3.77966011.3.92027624.4.07

6430 DATA 4.125.4.125.4.125.4.125
6440 DATA 2.0792053.2.2904182.2.64118049.3.06764295.3.43487191,3.74460242.4.0167
357
6450 DATA 4.26906294.4.45301104.4.55807916.4.62414591,4.76041382.4.92371929.5.07
893104
6460 DATA 5.18829011.5.28706835.5.37948565.5.46374572.5.54338324,5.61826745.5.68
927627
6470 DATA 5.75653645.5.82003175.5.86106883.5.88081358
6999 ! ///////// THERMODYNAMIC CONSTANT SUBR. /////////
7000 IF U7=1 THEN 7080
7020 FOR I=1 TO 13
7030 READ G(I)
7040 NEXT I
7050 FOR I=1 TO 13
7060 READ K(I)
7070 NEXT I
7080 IF W9=0 THEN W5=T(J6)
7090 IF W9=1 THEN W5=T(J5)
7095 IF W9=2 THEN W5=T(J7)
7100 FOR I=1 TO 13
7110 IF W5<G(I) THEN 7145
7140 NEXT I
7145 L=I
7150 C1=K(L-1)-(K(L-1)-K(L))/(G(L-1)-G(L))*(G(L-1)-W5) ! ..... LINEAR INTERPOL
7155 U7=1
7160 RETURN
7170 DATA 1.4.1.45.1.5.1.55.1.6.1.65.1.7.1.75.1.8.1.85.1.9.1.95.2
7180 DATA 223.61.274.73,333.03,399.27,472.97.554.27.643.58,738.02,837.52.939.43
7190 DATA 1039.44,1133.34,1213.43
```

```
1 ! //////////////////////////////////////////////////////////////
2 ! //////// "KERRY": TRANSFERS DATA FROM TAPE TO PRINTER //////
3 ! //////////////////////////////////////////////////////////////
10 CLEAR @ PRINTER IS 701.132
20 DISP "REMOVE PROGRAM TAPE AND INSTALL DATA TAPE" @ BEEP
30 DISP "WHEN COMPLETED. ENTER 1"
31 INPUT Y
32 IF Y=1 THEN 300 ELSE CLEAR @ BEEP @ GOTO 30
40 F$="C-G RAVINE"
41 PRINT USING 50 : "TIME","TEMP","PRES","M #"."C. FREQ","AMP"."Q"."SNR"."D-AMP"
."# PT",F$
50 IMAGE 4A.5X.4A.6X.5A.4X.3A.6X.7A.9X.4A.14X.1A.9X.3A.5X.5A.4X.4A.6X.10A
60 PRINT USING 70 : "(SEC)","(K)"."(HZ)","(VRMS)","(mV)"
70 IMAGE 5A.4X.5A,25X,4A,10X.6A.
80 PRINT
90 BEEP @ CLEAR @ DISP "DATA FILE NAME";
100 INPUT H$
110 ASSIGN# 1 TO H$
120 BEEP @ DISP "FIRST ":H$;" PT #"
130 INPUT K1
140 BEEP @ DISP "LAST ":H$:" PT #"
150 INPUT K2
160 FOR N=K1 TO K2
170 READ# 1.N ; T1.T.P.M.F.VO.O.S.V1,N.C
180 IMAGE 5D.4X.D.3D,4X.D.3D.5X.2D.6X.4D.3D.6X.D.4DE.7X.3D.3D.2X.2DC3D.2D.2X.4D.
D,4X.3D.7X.D.4DE
181 PRINT USING 180 ; T1.T.P.M.F.VO.Q.S.V1.N.C
190 IF N=K2 THEN 192 ELSE 191
191 NEXT N
192 BEEP @ DISP "DO YOU WANT TO LOOK AT MORE DATA? Y/N"
193 INPUT Z
194 IF Z=Y THEN 300 ELSE GOTO 195
195 ASSIGN# 1 TO *
200 END
300 DISP "ENTER PREAMP GAIN" @ BEEP
310 INPUT P$
320 DISP "ENTER FSS FROM 5204" @ BEEP
330 INPUT S$
340 DISP "ENTER MULTIP FROM 5204" @ BEEP
350 INPUT M$
360 DISP "ENTER TRANSMIT/RECEIVE" @ BEEP
370 INPUT K$
380 DISP "ENTER RUN NUMBER" @ BEEP
390 INPUT Z$
400 DISP "ENTER FIG NUMBER" @ BEEP
410 INPUT W$
415 FOR I=1 TO 132
416 PRINT "*";
417 NEXT I
420 PRINT "PREAMP=";P$."FSS=":S$."MULTIP=":M$,K$."RUN#":Z$."FIG#":W$
430 PRINT
440 GOTO 40
```

```
1 ! /////// "GETDAT": PULLS THERMOM CAL DATA FROM TAPE /////////
2 ! ////////////////////////////////////////////////////////////
10 ASSIGN# 1 TO "DATA11"
20 FOR I=1 TO 8
30 READ# 1.I : I.P,V,T.R
40 PRINT USING 45 : I,V.T,R
45 IMAGE 3D.1X.1DZ.4D.1X,1DZ.5D.2X.3DZ.5D
55 NEXT I
65 ASSIGN# 1 TO *
75 END
```

```
6000 ! //////// "SPLINE": CUBIC SPLINE TEMP FROM PRESS /////////
6001 ! ////////////////////////////////////////////////////////////
6005 DIM B(25),Z(29).D(4)
6010 INTEGER I.J.K
6020 FOR I=1 TO 29
6030 READ Z(I)
6040 NEXT I
6050 FOR I=1 TO 25
6060 READ B(I)
6070 NEXT I
6072 CLEAR @ BEEP @ DISP "INPUT VALUE OF PRESSURE(mmHg)."
6074 INPUT P
6076 CLEAR @ DISP "INPUT EXPECTED TEMP" @ INPUT T8
6077 CLEAR @ DISP
6078 DISP "  PRESS    TEMP       TEMP"
6079 DISP "          (TABLE)    (SPLINE)"
6080 P=P*1000
6110 P=LGT(P)
6120 T1=1 @ T2=4.215
6130 X=(T1+T2)/2
6140 I=0 @ J=22
6150 K=(I+J)/2
6160 IF J-I<=1 THEN 6200
6170 IF X>Z(K+4) THEN 6190
6180 J=K @ GOTO 6150
6190 I=K @ GOTO 6150
6200 FOR I=1 TO 4
6210 D(I)=B(I+J-1)
6220 NEXT I
6230 FOR K=1 TO 3
6240 FOR I=1 TO 4-K
6250 P8=X-Z(I+J+K-1)
6260 P9=Z(I+J+3)-X
6270 P3=1/(Z(I+J+3)-Z(I+J+K-1))
6280 D(I)=(P8*D(I+1)+P9*D(I))*P3
6290 NEXT I
6300 NEXT K
6310 IF ABS(D(1)-P)<.0001 THEN 6370
6320 IF D(1)>P THEN 6350
6330 T1=X
6340 GOTO 6130
6350 T2=X
6360 GOTO 6130
6370 D(1)=10^D(1)
6372 DISP USING 6373 : D(1)/1000.T8.X
6373 IMAGE 2DZ.4D, 3X.1D.4D. 6X.1D.4D.7/
6374 DISP @ BEEP @ DISP "ENTERING ANOTHER PRESSURE? (Y/N)"
6376 INPUT B$
6378 IF B$="Y" THEN 6072
6380 IF B$#"N" THEN 6374
6382 CLEAR @ BEEP @ DISP TAB(10);"THAT'S ALL"
6384 END
6390 DATA 1,1,1,1
6400 DATA 1.15105499,1.2876575,1.43202085,1.59832713,1.74054982,1.89959361,2.101
7899
6410 DATA 2.17601406,2.18321995,2.28846654,2.57937753,2.74048335,2.88959932,3.04
057357
6420 DATA 3.18965645,3.34056636,3.47966198,3.63056679,3.77966011,3.92027624,4.07
```

```
6430 DATA 4.125,4.125,4.125,4.125
6440 DATA 2.0792053,2.2904182,2.64118049,3.06764295,3.43487191,3.74460242,4.0167
357
6450 DATA 4.26906294,4.45301104,4.55807916,4.62414591,4.76041382,4.92371929,5.07
893104
6460 DATA 5.18829011,5.28706835,5.37948565,5.46374572,5.54338324,5.61826745,5.68
927627
6470 DATA 5.75653645,5.82003175,5.86106883,5.88081358
```

APPENDIX C

RAW DATA

```
##################################################################################################################################
PREAMP=1000        FSS=100MV          MULTIP=X1    .      EA/EB            RUN#14            FIG#1

TIME     TEMP     PRES     M #     C. FREQ       AMP              Q        SNR      D-AMP    # PT      C-6 RAVINE
(SEC)    (K)                        (HZ)        (VRMS)(mV)

 1178    1.647    6.955     1       410.541    5.3723E-005      447.257  1,859.24   250.0     1       8.0810E-005
 1374    1.647    6.970     2       615.491    1.2408E-004       69.055  4,294.21   250.0     2       1.8422E-001
 1570    1.648    6.985     3       817.549    9.7666E-005      427.357  3,379.97   250.0     3       3.5883E-004
 1766    1.648    6.997     4      1020.198    6.1003E-005      314.598  2,111.18   250.0     4       1.9276E-004
 1962    1.649    7.016     5      1222.494    4.8319E-005      216.189  1,672.20   250.0     5       1.9017E-005
 2149    1.649    7.017     6      1426.145    3.6346E-005      189.206  1,257.85   500.0     6       4.9947E-004
 2494    1.649    7.035     1       410.563    5.3656E-005      445.411  1,856.91   250.0     7       4.5311E-005
 2688    1.649    7.032     2       614.967    1.2348E-004      124.968  4,273.28   125.0     8       1.5032E-001
 2988    1.649    7.032     2       614.957    1.2673E-004      133.229  4,385.94   125.0     9       1.4070E-001
 3190    1.650    7.053     3       817.591    4.8743E-005      427.026  1,686.86   125.0    10       2.0736E-005
 3386    1.650    7.058     4      1020.239    6.1393E-005      323.198  2,124.67   250.0    11       9.7127E-005
 3582    1.650    7.064     5      1222.538    4.8375E-005      216.047  1,674.13   250.0    12       7.5379E-006
 3775    1.650    7.066     6      1426.188    3.6416E-005      188.323  1,260.26   500.0    13       4.6697E-004
 4114    1.651    7.079     1       410.575    5.3616E-005      447.244  1,855.52   250.0    14       3.0518E-005
 4314    1.651    7.079     2       614.773    1.2298E-004      260.071  4,255.97    62.5    15       7.9941E-002
 4517    1.651    7.085     3       817.608    4.8641E-005      424.482  1,683.36   125.0    16       1.2699E-005
 4713    1.651    7.088     4      1020.258    6.1308E-005      323.038  2,121.73   250.0    17       8.8040E-005
 4913    1.651    7.092     5      1222.553    4.8405E-005      216.394  1,675.20   250.0    18       7.4657E-006
 5108    1.652    7.099     6      1426.203    3.6482E-005      187.411  1,262.57   500.0    19       4.3042E-004
 5451    1.652    7.103     1       410.581    5.3560E-005      446.828  1,853.57   250.0    20       2.4242E-005
 5650    1.652    7.106     2       614.752    9.8822E-005      485.800  3,419.98    31.3    21       6.5543E-004
 5854    1.652    7.112     3       817.619    4.8637E-005      424.922  1,683.20   125.0    22       9.7365E-006
 6052    1.652    7.115     4      1020.270    6.1225E-005      322.555  2,118.85   250.0    23       8.6328E-005
 6252    1.652    7.118     5      1222.566    4.8410E-005      216.457  1,675.35   250.0    24       8.1967E-006
 6448    1.652    7.123     6      1426.215    3.6530E-005      186.846  1,264.20   500.0    25       4.4379E-004
 7004    1.653    7.130     1       410.589    5.3720E-005      454.124  1,859.13   250.0    26       6.1117E-005
 7302    1.653    7.130     1       410.589    5.3710E-005      453.850  1,858.77   250.0    27       6.0964E-005
 7504    1.653    7.140     2       614.756    4.9895E-005      492.187  1,726.73    15.6    28       8.5261E-005
```

```
####################################################################################################################################
PREAMP=100           FSS=100MV            MULTIP=X10           EB/EA                RUN#14               FIG#2

TIME     TEMP      PRES      M #       C. FREQ         AMP               Q          SNR     D-AMP   # PT      C-G RAVINE
(SEC)    (K)                            (HZ)          (VRMS)(mV)

  482    1.659     7.302      1        410.603     1.0100E-004        458.394      210.62   500.0     34      4.9158E-004
 1102    1.659     7.302      1        410.603     1.0102E-004        458.561      210.65   500.0     35      4.9141E-004
 1307    1.659     7.326      2        614.778     1.0187E-004        489.885      212.42    31.3     36      4.2782E-003
 1716    1.659     7.326      2        614.778     1.0197E-004        491.223      212.63    31.3     37      4.2683E-003
 1921    1.660     7.345      3        817.650     9.3640E-005        431.947      195.27   250.0     38      9.3867E-005
 2125    1.660     7.348      4       1020.332     1.0787E-004        316.011      224.95   500.0     39      4.9960E-004
 2325    1.660     7.356      5       1222.748     8.3212E-005        220.554      173.52   500.0     40      8.1658E-006
 2519    1.661     7.363      6       1426.063     3.4822E-005        192.996       72.61   500.0     41      3.8978E-003
 2869    1.661     7.372      1        410.598     4.9565E-005        456.920      103.36   250.0     42      1.8618E-004
 3073    1.661     7.379      2        614.769     5.1365E-005        507.340      107.11    15.6     43      2.1820E-003
 3377    1.661     7.379      2        614.768     5.1009E-005        496.331      106.37    15.6     44      2.0143E-003
 3583    1.662     7.389      3        817.640     9.3623E-005        431.475      195.23   250.0     45      4.4685E-004
 3781    1.662     7.399      4       1020.310     5.7315E-005        324.568      119.52   250.0     46      1.1326E-004
 3978    1.662     7.402      5       1222.729     8.3351E-005        221.071      173.81   500.0     47      1.2128E-005
 4175    1.662     7.408      6       1426.220     3.4679E-005        185.698       72.32   500.0     48      3.1921E-004
```

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##################################################################################################################################
PREAMP=100          FSS=100MV          MULTIP=X10       -- T/EA              RUN#14            FIG#3

TIME     TEMP     PRES     M #      C. FREQ       AMP                   Q          SNR      D-AMP    # PT      C-G RAVINE
(SEC)    (K)                         (HZ)         (VRMS)(mV)

  572    1.663    7.444     1       205.330     1.2048E-004          124.892     332.25    50.0      49       1.6071E-001
  770    1.663    7.442     2       307.469     1.2253E-004          110.042     337.92    50.0      50       1.6865E-001
  975    1.663    7.442     3       408.912     1.0973E-004          434.278     302.63    50.0      51       4.7166E-004
 1178    1.663    7.443     4       510.116     4.7497E-005          327.307     130.99    50.0      52       7.5799E-006
 1380    1.664    7.449     5       611.279     2.9348E-005          217.229      80.94    50.0      53       5.7766E-006
 1587    1.664    7.452     6       713.234     1.4535E-005          189.340      40.08    50.0      54       7.9015E-006
 1785    1.664    7.455     7       814.110     1.4698E-005          303.535      40.53    50.0      55       9.8763E-006
 2191    1.664    7.460     1       205.295     8.0047E-005          452.021     220.76    25.0      56       4.8957E-004
 2395    1.664    7.463     2       307.369     2.5519E-005          472.238      70.38    12.5      57       3.6652E-003
 2597    1.664    7.464     3       408.811     1.0950E-004          432.417     301.99    50.0      58       8.9240E-005
 2801    1.664    7.465     4       510.112     4.7508E-005          327.362     131.02    50.0      59       6.7835E-006
 3003    1.664    7.466     5       611.276     2.9282E-005          216.637      80.76    50.0      60       4.3406E-006
 3209    1.664    7.472     6       713.232     5.7668E-005          188.002     159.04   100.0      61       4.2014E-005
 3404    1.664    7.471     7       814.100     5.8371E-005          302.547     160.98   100.0      62       5.7759E-005
```

```
##################################################################################################################################
PREAMP=100          FSS=100MV          MULTIP=X10          T/EB              RUN#14            FIG#3

TIME     TEMP     PRES     M #      C. FREQ       AMP                   Q          SNR      D-AMP    # PT      C-G RAVINE
(SEC)    (K)                         (HZ)         (VRMS)(mV)

 3761    1.664    7.474     1       205.292     9.9649E-005          456.198     274.82    50.0      63       2.0665E-005
 4064    1.664    7.474     1       205.292     9.9640E-005          456.048     274.79    50.0      64       2.0530E-005
 4267    1.664    7.476     2       307.375     3.4645E-005          497.076      95.55    12.5      65       6.3169E-005
 4470    1.665    7.479     3       408.804     2.6297E-005          431.030      72.52    25.0      66       7.7832E-006
 4672    1.665    7.479     4       510.112     6.5831E-005          326.220     181.55    50.0      67       4.3282E-006
 4877    1.665    7.493     5       611.375     3.4846E-005          216.959      96.10    50.0      68       2.5225E-004
 5083    1.665    7.485     6       713.348     6.0512E-005          187.141     166.89   100.0      69       4.8786E-004
 5278    1.665    7.488     7       814.221     3.2539E-005          299.613      89.74   100.0      70       2.6419E-004
 5845    1.665    7.491     1       205.290     2.4797E-005          460.469      68.39    25.0      71       7.2761E-006
 6149    1.665    7.491     1       205.290     2.4789E-005          460.006      68.36    25.0      72       7.1876E-006
 6351    1.665    7.499     2       307.372     3.4754E-005          503.714      95.85    12.5      73       2.6717E-005
 6556    1.665    7.497     3       408.799     1.0596E-004          440.636     292.21    50.0      74       3.2138E-004
 6759    1.665    7.499     4       510.108     6.5763E-005          326.922     181.36    50.0      75       1.4110E-006
 6959    1.665    7.497     5       611.369     3.4810E-005          216.779      96.00    50.0      76       2.3568E-004
 7166    1.665    7.496     6       713.347     6.0480E-005          186.958     166.80   100.0      77       4.6125E-004
 7362    1.665    7.496     7       814.220     3.2488E-005          299.638      89.60   100.0      78       2.6949E-004
```

```
################################################################################################################
PREAMP=100          FSS=100MV          MULTIP=X10          EB/EA          RUN#14          .     FIG#4

TIME     TEMP      PRES      M #       C. FREQ         AMP                Q          SNR     D-AMP     # PT        C-G RAVINE
(SEC)    (K)                            (HZ)          (VRMS)(mV)

 1844    1.471     2.886      1        225.944      6.0730E-005         180.979      63.86    500.0     146        4.3409E-002
 2473    1.471     2.886      1        225.945      6.0848E-005         181.755      63.99    500.0     147        4.3405E-002
 2680    1.471     2.896      2        397.614      1.1540E-004         333.124     121.35    500.0     148        4.4630E-004
 2886    1.471     2.900      3        596.191      1.2393E-004          39.305     130.32    250.0     149        1.7931E-001
 3095    1.471     2.900      4        791.859      1.2109E-004         217.721     127.34    250.0     150        4.4149E-002
 3305    1.472     2.908      5        988.613      6.5895E-005         226.724      69.29    250.0     151        2.3543E-003
 3510    1.472     2.909      6       1185.286      5.7196E-005         198.548      60.15   1000.0     152        8.5665E-005
 3717    1.472     2.914      7       1381.842      3.0711E-005         223.312      32.30    500.0     153        5.7340E-005
 3916    1.472     2.914      8       1576.916      3.5456E-005         295.109      37.29   1000.0     154        1.7420E-005
 4282    1.472     2.919      1       1558.791      5.2322E-005           2.176      55.02   3500.0     155        3.7910E-003
 4593    1.472     2.919      1       1558.861      5.2326E-005           2.176      55.03   3500.0     156        3.7910E-003
 4798    1.472     2.922      2        397.791      5.7572E-005         339.016      60.54    250.0     157        2.3866E-004
 5007    1.473     2.928      3        595.991      1.2331E-004          70.520     129.67    125.0     158        1.7590E-001
 5218    1.473     2.932      4        792.129      1.1855E-004         194.589     124.66    250.0     159        8.3408E-002
 5428    1.473     2.934      5        989.097      6.6080E-005         232.583      69.49    250.0     160        4.7951E-004
 5634    1.473     2.940      6       1185.884      5.8519E-005         199.139      61.54   1000.0     161        7.6838E-005
 5839    1.474     2.945      7       1382.569      3.0626E-005         222.414      32.21    500.0     162        6.4057E-005
 6038    1.474     2.947      8       1577.790      3.5444E-005         294.717      37.27   1000.0     163        1.8516E-005

################################################################################################################
PREAMP=100          FSS=100MV          MULTIP=X10          EB/EA          RUN#14          FIG#4

TIME     TEMP      -PRES     M #       C. FREQ         AMP                Q          SNR     D-AMP     # PT        C-G RAVINE
(SEC)    (K)                            (HZ)          (VRMS)(mV)

 1627    1.471     2.899      1        212.541      -.6053E-004         -58.023     -77.52    125.0     136        4.2126E-001
 2037    1.471     2.899      1        212.295      -.5602E-004         -43.071     -71.75    125.0     137        3.9478E-001
 2247    1.470     2.867      2        397.580      1.1617E-004         344.826     148.78    500.0     138        1.0751E-003
 2457    1.469     2.862      3        595.712      1.2426E-004          72.428     159.14    125.0     139        1.5640E-001
 2764    1.469     2.862      3        595.682      1.2753E-004          77.147     163.32    125.0     140        1.4844E-001
 2976    1.469     2.852      4        791.493      7.7214E-005         314.226      98.89    125.0     141        4.1177E-004
 3184    1.469     2.847      5        987.916      6.6476E-005         235.701      85.13    250.0     142        1.6505E-004
 3386    1.468     2.843      6       1184.371      5.5440E-005         199.161      71.00   1000.0     143        9.6177E-005
 3595    1.468     2.842      7       1380.659      3.0825E-005         223.821      39.48    500.0     144        6.0150E-005
 3795    1.468     2.840      8       1575.466      3.5594E-005         296.500      45.58   1000.0     145        1.1072E-005
```

```
####################################################################################################################
PREAMP=100          FSS=100MV          MULTIP=X10          EA/EB          RUN#14          FIG#5

TIME     TEMP     PRES     M #     C. FREQ     AMP                 Q        SNR       D-AMP    # PT     C-6 RAVINE
(SEC)    (K)                        (HZ)       (VRMS)(mV)

 1808    1.476    2.997    1        398.422    6.0673E-005      358.268   2,192.74   250.0     79      6.9689E-005
 2013    1.475    2.976    2        597.511    1.2370E-004       44.878   4,470.62   250.0     80      1.3991E-001
 2216    1.474    2.954    3        792.865    1.2212E-004      226.171   4,413.66   250.0     81      4.6972E-002
 2422    1.474    2.946    4        989.720    7.0541E-005      229.346   2,549.40   250.0     82      1.0413E-003
 2627    1.473    2.938    5       1187.178    3.0973E-005      222.857   1,119.38   500.0     83      6.6473E-003
 2826    1.472    2.915    6       1382.358    3.7302E-005      228.557   1.348.12   500.0     84      4.8271E-004
 3023    1.471    2.899    7       1576.943    4.0116E-005      303.478   1,449.81  1000.0     85      1.8448E-006
 3700    1.468    2.842    1        397.275    6.0897E-005      340.619   2,200.86   250.0     86      6.0304E-005
 3907    1.468    2.835    2        595.190    1.2293E-004       72.068   4,442.68   125.0     87      1.7130E-001
 4213    1.468    2.835    2        595.171    1.2638E-004       77.307   4,567.55   125.0     88      1.5931E-001
 4421    1.467    2.820    3        790.949    8.0348E-005      304.479   2,903.82   125.0     89      2.0261E-004
 4627    1.467    2.819    4        987.305    7.0328E-005      238.870   2,541.68   250.0     90      1.4932E-004
 4831    1.467    2.821    5       1184.615    5.1898E-005      217.713   1,875.63  1000.0     91      1.1473E-002
 5037    1.467    2.823    6       1380.018    3.7731E-005      222.172   1,363.60   500.0     92      9.2207E-005
 5232    1.467    2.825    7       1574.881    4.0059E-005      294.543   1,447.74  1000.0     93      3.1634E-006
 5906    1.469    2.847    1        397.369    6.1000E-005      336.283   2,204.58   250.0     94      7.7867E-005
 6113    1.469    2.852    2        595.081    1.2295E-004      144.024   4,443.36    62.5     95      9.5399E-002
 6418    1.469    2.852    2        595.083    1.2561E-004      151.762   4,539.73    62.5     96      8.9233E-002
 6624    1.470    2.870    3        791.731    7.9090E-005      299.873   2,858.37   125.0     97      9.3958E-005
 6931    1.470    2.870    3        791.732    7.9066E-005      299.523   2,857.48   125.0     98      9.2936E-005
 7139    1.470    2.881    4        988.581    6.9696E-005      233.717   2,518.87   250.0     99      5.6483E-004
 7450    1.470    2.881    4        988.580    6.9814E-005      234.983   2,523.13   250.0    100      5.4568E-004
 7652    1.471    2.891    5       1186.274    5.5701E-005      218.639   2,013.06  1000.0    101      1.6162E-002
 8064    1.471    2.891    5       1186.267    5.5910E-005      221.328   2,020.62  1000.0    102      1.6098E-002
 8271    1.471    2.901    6       1382.031    7.4883E-005      230.499   2,706.32  1000.0    103      1.9229E-003
 8467    1.471    2.901    7       1577.121    3.9999E-005      297.281   1,445.59  1000.0    104      4.7321E-006
 9143    1.472    2.908    1        397.822    6.0913E-005      341.071   2,201.44   250.0    105      6.2201E-005
 9451    1.472    2.908    1        397.822    6.0919E-005      341.160   2,201.63   250.0    106      6.2170E-005
 9656    1.472    2.912    2        595.726    1.2005E-004      333.375   4,338.81    31.3    107      9.0220E-003
 9961    1.472    2.912    2        595.725    1.2096E-004      339.594   4,371.64    31.3    108      8.4295E-003
10173    1.472    2.919    3        792.433    7.7971E-005      307.668   2,817.91   125.0    109      1.9590E-004
10376    1.472    2.919    4        989.290    1.1737E-004      162.714   4,241.65   500.0    110      4.2809E-002
10581    1.472    2.922    5       1186.996    9.9262E-005      216.426   3,587.40  2000.0    111      5.0562E-002
10998    1.472    2.922    5       1186.992    9.9521E-005      218.274   3,596.74  2000.0    112      5.0464E-002
```

Run 15

T= 1.53°   EA/EB

```
PREAMP= 100  FSS=100mv  MULTIP=110

TIME    TEMP      PRES      M #      C. FREQ        AMP.             Q          SNR   D-AMP     # PT       C-S RAVINE
(SEC)   (K)                           (HZ)          (Vrms)                            (mV)

 558    1.539  4.307E+000   1        405.25836   1.2175E-004     247.3145      791   1000       1       6.1187E-002
 753    1.539  4.306E+000   2        606.77315   1.2353E-004     133.9092      803   1000       2       6.7318E-002
 949    1.539  4.303E+000   3        807.06781   7.6528E-005     318.1870      497   1000       3       1.1597E-003
1147    1.539  4.304E+000   4      1,007.65601   5.9766E-005     293.3300      388   1000       4       1.1637E-003
1345    1.539  4.302E+000   5      1,208.48755   2.6054E-005     276.9710      169   1000       5       3.7399E-004
1534    1.539  4.303E+000   6      1,409.55426   9.9363E-006     289.4748       65   1000       6       8.6439E-005


GONE TO MEASURE OUE TO AMPLITUDE AT TIME  1588.492   MODE  1
COULD NOT FIND 3dB DOWN PARAMETER
 2090   1.539  4.302E+000   1        405.27994   8.2836E-005     380.8350      538    500       7       1.0421E-003
 2286   1.539  4.299E+000   2        606.64945   1.2206E-004     241.1968      793    500       8       5.2554E-002
 2486   1.539  4.298E+000   3        807.04418   7.6411E-005     320.6333      497   1000       9       5.9708E-004
 2685   1.539  4.299E+000   4      1,007.68094   5.9094E-005     285.2036      384   1000      10       4.0620E-004
 2882   1.539  4.303E+000   5      1.208.51861   4.2292E-005     295.7761      275   2000      11       7.6480E-004
 3075   1.539  4.296E+000   6      1,409.73558   2.8513E-005     287.9521      185   3500      12       2.8447E-004


 GONE TO MEASURE DUE TO AMPLITUDE AT TIME  3130.296   MODE  1
 3422   1.539  4.295E+000   1        405.26371   8.1939E-005     376.4119      533    500      13       4.8784E-004
 3618   1.539  4.299E+000   2        606.65064   9.6125E-005     400.7547      625    250      14       5.6629E-004
 3817   1.539  4.301E+000   3        807.08492   7.6360E-005     320.1370      496   1000      15       6.9354E-004
 4019   1.539  4.301E+000   4      1,007.74889   5.9243E-005     287.1363      385   1000      16       4.1511E-004
 4217   1.539  4.305E+000   5      1,208.63369   4.2377E-005     284.5039      275   2000      17       6.6593E-004
 4411   1.539  4.306E+000   6      1,409.91306   2.8245E-005     288.6126      184   3500      18       2.5215E-004


 GONE TO MEASURE DUE TO AMPLITUDE AT TIME  4467.397   MODE  1
 4762   1.539  4.308E+000   1        405.34731   8.2304E-005     376.2451      535    500      19       2.4362E-004
 COULD NOT FIND 3dB DOWN PARAMETER
 5061   1.539  4.308E+000   1        405.34724   8.2315E-005     376.4501      535    500      20       2.4339E-004
 5260   1.539  4.308E+000   2        606.77581   5.1379E-005     409.6290      334    125      21       2.5133E-004
 5466   1.539  4.310E+000   3        807.22421   7.7056E-005     312.3438      501   1000      22       3.3716E-004
 5666   1.539  4.311E+000   4      1,007.91961   5.9293E-005     286.4070      385   1000      23       3.8713E-004
 5864   1.539  4.311E+000   5      1,208.84002   4.2310E-005     283.2952      275   2000      24       4.9920E-004
 6059   1.539  4.312E+000   6      1,410.15510   2.8105E-005     286.1372      183   3500      25       2.5658E-004
```

Run 15

```
GONE TO MEASURE DUE TO AMPLITUDE AT TIME 6113.254   MODE  6                EZ/EA
COULD NOT FIND 3dB DOWN PARAMETER
 6620    1.539  4.309E+000   1         405.40063   6.2691E-005    388.3066    407    500     26     2.2162E-003
COULD NOT FIND 3dB DOWN PARAMETER
 6925    1.539  4.309E+000   1         405.40075   6.2752E-005    389.5023    408    500     27     2.2112E-003
 7130    1.537  4.263E+000   2         606.61222   4.5013E-005    433.4483    293    125     28     4.5553E-004
 7333    1.536  4.235E+000   3         806.79715   6.4937E-005    314.1135    422   1000     29     5.6455E-004
 7535    1.534  4.203E+000   4       1,006.91695   5.1066E-005    265.5433    332    500     30     1.0330E-003
 7741    1.533  4.173E+000   5       1,207.44429   6.5027E-005    276.7008    423   2000     31     1.0144E-003
 7934    1.532  4.150E+000   6       1,407.84448   3.7978E-005    294.4354    247   3500     32     2.3195E-003

Time    TEMP    press.   mode      f          Vout           Q          SNR   Vin      =      G-G.
                                                                             (mv)
GONE TO MEASURE DUE TO AMPLITUDE AT TIME  9908.872   MODE  5
10203    1.533  4.179E+000   1         404.96053   6.3842E-005    334.0217    415    500     33     1.2084E-003
10405    1.533  4.177E+000   2         606.28487   4.6350E-005    422.4375    301    125     34     8.3784E-004
10611    1.532  4.148E+000   3         806.11048   6.4280E-005    313.8499    418   1000     35     3.7772E-004
10817    1.531  4.131E+000   4       1,006.27962   5.2326E-005    263.9542    340    500     36     9.1603E-004
11018    1.531  4.127E+000   5       1,206.94399   6.5053E-005    271.4878    423   2000     37     2.0094E-003
11212    1.531  4.125E+000   6       1,407.65800   3.7616E-005    284.7029    244   3500     38     1.3920E-003


GONE TO MEASURE DUE TO AMPLITUDE AT TIME  11360.704   MODE  1
11655    1.531  4.129E+000   1         404.78207   3.6458E-005    386.0625    237    250     39     3.2961E-004
11855    1.531  4.130E+000   2         605.90718   4.5583E-005    422.2190    296    125     40     4.5442E-004
12060    1.531  4.133E+000   3         805.98866   6.4911E-005    304.6058    422   1000     41     2.2427E-003
12265    1.531  4.132E+000   4       1,006.32658   5.2342E-005    256.8240    340    500     42     4.7634E-004
12466    1.531  4.137E+000   5       1,207.12201   6.5391E-005    269.1062    425   2000     43     1.0031E-003
12657    1.532  4.139E+000   6       1,407.88873   3.7832E-005    285.6657    246   3500     44     1.8187E-003
```

T/EA Run 15

```
PREAMP= 100  FSS=100mv  MULTIP=X10

TIME    TEMP      PRES      M #      C. FREQ       AMP.               Q           SNR   D-AMP   # PT        C-6 RAVINE
(SEC)   ( K )                         (HZ)        (Vrms)                          .     (mV)

 1426   1.533  4.165E+000   1       202.47173   7.0650E-005      386.2587       357     25      45        1.5649E-004
 1628   1.532  4.156E+000   2       303.06088   1.0504E-004      420.7115       531     25      46        3.0370E-004
 1829   1.532  4.145E+000   3       403.11845   3.2022E-005      320.4392       162     25      47        2.0546E-004
 2034   1.532  4.145E+000   4       503.24461   3.9907E-005      270.5780       202     25      48        6.4248E-003
 2237   1.532  4.144E+000   5       603.81868   4.8723E-005      272.5283       246     50      49        5.0342E-005
 2432   1.532  4.145E+000   6       704.06380   5.4844E-005      297.2491       277    100      50        3.5364E-003


GONE TO MEASURE DUE TO AMPLITUDE AT TIME  2489.553   MODE  2
 2785   1.532  4.146E+000   1       202.47544   7.0824E-005      388.3903       358     25      51        3.3513E-004
COULD NOT FIND 3dB DOWN PARAMETER
 3088   1.532  4.146E+000   1       202.47545   7.0806E-005      388.0710       358     25      52        3.3465E-004
 3268   1.532  4.151E+000   2       303.07832   2.6279E-005      418.3591       133     13      53        2.9156E-004
 3494   1.532  4.148E+000   3       403.13020   3.1983E-005      309.5326       162     25      54        1.0576E-004
 3699   1.532  4.149E+000   4       503.30842   3.9540E-005      250.8825       200     25      55        1.1607E-003
 3902   1.532  4.151E+000   5       603.85709   4.8737E-005      272.7888       247     50      56        6.1796E-005
 4100   1.532  4.150E+000   6       704.11569   5.4801E-005      294.8096       277    100      57        2.4275E-003
```

T=1.53°K

T/EB

```
GONE TO MEASURE DUE TO AMPLITUDE AT TIME  4155.673   MODE  6
 4452   1.532  4.147E+000   1       202.46911   9.7031E-005      389.8695       491     50      58        7.0727E-004
Error detected, mode  2  ERRL =  1980  ERRN =  55
 4862   1.532  4.147E+000   1       202.46912   9.6951E-005      388.8644       490     50      59        6.9855E-004
 5063   1.532  4.144E+000   2       303.07603   7.3542E-005      421.4043       372     50      60        2.9594E-004
 5266   1.532  4.144E+000   3       403.22495   5.6235E-005      296.5188       284    100      61        1.3171E-003
 5469   1.532  4.144E+000   4       503.43100   3.3297E-005      254.4382       168    100      62        8.6769E-005
 5676   1.532  4.147E+000   5       603.89437   2.3334E-005      267.7471       118    100      63        4.0175E-005
 5874   1.532  4.151E+000   6       704.27995   1.5936E-005      289.2337        81    100      64        1.7446E-005


GONE TO MEASURE DUE TO AMPLITUDE AT TIME  5975.657   MODE  1
 6271   1.532  4.157E+000   1       202.49185   9.7514E-005      393.1862       493     50      65        5.1500E-004
 6476   1.532  4.156E+000   2       303.11235   7.3536E-005      421.5481       372     50      66        3.9340E-004
 6680   1.532  4.154E+000   3       403.27262   5.6426E-005      297.6555       285    100      67        1.5544E-003
 6887   1.532  4.153E+000   4       503.47985   3.3369E-005      257.0193       169    100      68        3.7238E-005
 7090   1.532  4.153E+000   5       603.97813   2.3340E-005      267.8227       118    100      69        3.0247E-005
 7289   1.532  4.150E+000   6       704.40096   1.5924E-005      291.9000        81    100      70        7.7820E-006
```

```
PREAMP= 100  FSS=100mv  MULTIP=X10
```

EA/EB T = 1.95K Run 15

```
TIME    TEMP      PRES     M #      C. FREQ        AMP.              Q        SNR    D-AMP    # PT       C-S RAVINE
(SEC)   ( K )                        (HZ)         (Vrms)                              (mV)

 1668   1.777  2.042E+001   1       360.89830   1.2112E-004     623.7043    1.801    500      71      9.8873E-003
 1872   1.777  2.041E+001   2       540.45590   6.6918E-005     546.1371      995    500      72      1.7490E-002
 2075   1.777  2.041E+001   3       718.28436   1.0440E-004     476.6407    1,552    500      73      1.9352E-003
 2281   1.777  2.042E+001   4       896.83800   6.6851E-005     252.3626      994    500      74      1.3144E-002
 2486   1.777  2.043E+001   5    1,076.35295    3.9063E-005     293.8991      581   1000      75      3.6082E-004
 2681   1.777  2.043E+001   6    1,254.92225    3.4875E-005     363.7131      519   2000      76      1.2858E-003



Error detected, mode  1  ERRL =  1980  ERRN =  55
 3246   1.776  2.046E+001   1       360.67858   6.7934E-005     765.7112    1,010    250      77      2.7818E-004
 3451   1.776  2.047E+001   2       539.83214   6.5029E-005     529.9967      967    500      78      5.1324E-003
 3656   1.776  2.047E+001   3       717.38728   5.9447E-005     513.8104      884    250      79      8.4790E-005
 3862   1.776  2.048E+001   4       895.78256   6.6711E-005     245.4899      992    500      80      6.6520E-003
 4066   1.776  2.049E+001   5    1,075.07730    3.9366E-005     294.5354      585   1000      81      3.1494E-004
 4263   1.776  2.050E+001   6    1,253.46822    3.4869E-005     359.3887      519   2000      82      1.4347E-003


COULD NOT FIND 3dB DOWN PARAMETER
 4827   1.776  2.052E+001   1       360.28699   6.7486E-005     754.9505    1,004    250      83      5.2638E-004
COULD NOT FIND 3dB DOWN PARAMETER
 5134   1.776  2.052E+001   1       360.28706   6.7555E-005     757.4384    1,005    250      84      5.1981E-004
 5341   1.775  2.053E+001   2       539.15315   6.4341E-005     523.8348      957    500      85      5.2656E-003
 5548   1.775  2.054E+001   3       716.51033   6.0024E-005     521.8238      893    250      86      1.3993E-004
 5754   1.775  2.054E+001   4       894.69600   6.6748E-005     242.6665      993    500      87      6.6777E-003
 5959   1.775  2.055E+001   5    1,073.82880    3.9722E-005     294.8095      591   1000      88      3.1860E-004
 6158   1.775  2.055E+001   6    1,252.04177    3.4941E-005     358.3107      520   2000      89      1.5672E-003


 6509   1.775  2.056E+001   1       359.96680   6.7246E-005     766.8375    1,000    250      90      1.3919E-003
 6713   1.775  2.057E+001   2       538.76764   6.4055E-005     530.4363      953    500      91      5.7108E-003
```

EB/EA

T = 1.95 °K

```
 6920   1.775  2.057E+001   3       715.99789   6.0333E-005     522.2449      897    250      92      1.2293E-004
 7123   1.774  2.058E+001   4       894.10242   6.0792E-005     252.0081      904    500      93      8.2292E-002
 7329   1.774  2.058E+001   5    1,073.11317    5.0729E-005     266.1861      754   1000      94      4.5066E-004
 7528   1.774  2.059E+001   6    1,251.21594    4.1617E-005     332.1528      619   2000      95      7.0670E-003


 7881   1.774  2.060E+001   1       359.71076   5.5179E-005     767.2260      821    250      96      1.5943E-003
 8086   1.774  2.060E+001   2       538.40319   5.6699E-005     527.4866      843    500      97      4.4594E-003
 8292   1.774  2.061E+001   3       715.50319   5.7593E-005     545.1621      856    250      98      7.1486E-005
 8499   1.774  2.061E+001   4       893.42434   5.9592E-005     220.5541      886    500      99      5.9354E-003
 8707   1.774  2.062E+001   5    1,072.38714    5.0981E-005     266.1808      758   1000     100      5.5928E-004
 8904   1.774  2.062E+001   6    1,250.36289    4.2070E-005     334.4867      626   2000     101      1.6248E-002


 9260   1.774  2.063E+001   1       359.47747   5.4578E-005     763.6972      812    250     102      4.0731E-004
 9467   1.774  2.063E+001   2       538.06841   5.6073E-005     514.7377      834    500     103      4.5694E-003
 9670   1.773  2.064E+001   3       715.05769   5.7870E-005     544.4851      861    250     104      3.1696E-004
 9875   1.773  2.065E+001   4       892.84067   5.9858E-005     223.1621      890    500     105      8.0660E-003
10076   1.773  2.065E+001   5    1,071.73192    5.1223E-005     266.2014      762   1000     106      6.0749E-004
10272   1.773. 2.065E+001   6    1,249.59383    4.1934E-005     331.2061      624   2000     107      1.7715E-002
```

Run 15

T=1.3 °K   EC/EA

```
PREAMP= 100  FSS=100mv  MULTIP=X10

TIME    TEMP      PRES      M #     C. FREQ        AMP.            Q          SNR   D-AMP   # PT      C-G RAVINE
(SEC)   ( K )                        (HZ)         (Vrms)                             (mV)

 1223   1.788  1.275E+001   1       400.27203   6.4345E-005    635.9986      87     350     183     3.6307E-003
 1434   1.788  1.276E+001   2       599.11563   1.1799E-004    525.6730     159     350     184     1.5831E-002
 1647   1.788  1.276E+001   3       796.31935   5.9109E-005    382.7345      80     350     185     1.9467E-003
 1858   1.788  1.277E+001   4       994.49679   9.3185E-005    255.3855     126     700     186     1.6860E-002
 2058   1.788  1.278E+001   5     1,194.19908   5.4312E-005    257.7108      73    1400     187     8.4315E-003

COULD NOT FIND 3dB DOWN PARAMETER
 2620   1.788  1.280E+001   1       400.10539   6.3768E-005    634.0055      86     350     188     1.4629E-003
 2828   1.788  1.281E+001   2       598.85966   6.4348E-005    540.7303      87     175     189     1.3911E-003
 3039   1.789  1.281E+001   3       796.02285   5.9868E-005    381.8053      79     350     190     1.1063E-003
 3252   1.789  1.282E+001   4       994.13663   9.2515E-005    250.3845     125     700     191     1.3580E-002
 3453   1.789  1.282E+001   5     1,193.78456   5.4113E-005    246.6109      73    1400     192     8.2602E-003
```

T=1.5 °K   T|EA

```
PREAMP= 100  FSS=100mv  MULTIP=X10

TIME    TEMP      PRES      M #     C. FREQ        AMP.            Q          SNR   D-AMP   # PT      C-G RAVINE
(SEC)   ( K )                        (HZ)         (Vrms)                             (mV)

 1314   1.789  1.286E+001   1       199.94982   6.8578E-005    633.0589       6      25     193     1.0078E-003
 1523   1.789  1.287E+001   2       299.24974   9.6033E-005    556.0446       9      25     194     4.9395E-004
 1733   1.789  1.287E+001   3       397.83246   5.0084E-005    382.9991       4      25     195     3.3663E-005
 1944   1.789  1.288E+001   4       496.90643   9.6016E-005    255.0396       9      50     196     5.5341E-003
 2144   1.789  1.288E+001   5       596.22575   1.1815E-004    173.9125      11     100     197     5.6798E-002
```

T=1.5°K   T/EB

```
COULD NOT FIND 3dB DOWN PARAMETER                                                                 9.2389E-005
```

APPENDIX D

REDUCED DATA

```
                                         RUN # 14
                                      DATA REDUCTION

 E/E  ( 82  TO  85 )
 T/EA ( 171  TO  174 )    T/EB ( 215  TO  218 )

          T          r         F        r        STr       STu      Ua - Ub       S(A)        S(B)        STu/STr      >1
         avg                  avg                          avg
MODE     (K)        (K)       (Hz)     (Hz)     (uK)      (uK)      (uK)         (V/K)       (V/K)
----------------------------------------------------------------------------------------------------------------------------
  5    1.4543     .0042    987.437   1.688     2.183     2.433       .184       42.55       68.16        1.115        YES
  6    1.4540     .0039   1184.183   2.140     1.461     1.649       .066       46.89       13.95        1.129        YES
  7    1.4535     .0031   1380.016   1.726     5.485     6.560      -.038       26.09       29.33        1.196        YES
  8    1.4533     .0027   1574.573   1.767     5.894     7.158      -.220       18.70       16.54        1.215        YES


 E/E  ( 89  TO  93 )
 T/EA ( 183  TO  187 )    T/EB ( 222  TO  226 )

  4    1.4528     .0029    790.835    .612      .941      .938       .004       67.94       71.27         .997        NO
  5    1.4539     .0042    987.468   1.119     2.193     2.150      -.362       40.01       67.51         .981        NO
  6    1.4541     .0043   1184.367   1.004     1.583     1.592       .022       42.34       12.91        1.006        YES
  7    1.4543     .0045   1380.522   1.505     1.314     1.466      -.350       25.72       30.33        1.116        YES
  8    1.4546     .0048   1575.323   1.640     5.847     7.308       .100       18.87       16.59        1.250        YES


 E/E  ( 98  TO  98 )
 T/EA ( 182  TO  182 )    T/EB ( 221  TO  221 )

  4    1.4539     .0027    725.735    .        1.680     1.036      -.193       38.03      128.73         .617        NO


 E/E  ( 100  TO  101 )
 T/EA ( 184  TO  185 )    T/EB ( 223  TO  224 )

  5    1.4553     .0037    987.893   1.215     2.168     2.150      -.362       40.46       68.28         .992        NO
  6    1.4557     .0037   1184.920   1.376     1.519     1.592       .022       44.11       13.45        1.048        YES


 E/E  ( 102  TO  104 )
 T/EA ( 185  TO  187 )    T/EB ( 216  TO  218 )

  6    1.4552     .0043   1184.675   1.709     1.524     1.609      -.012       43.97       13.38        1.056        YES
  7    1.4557     .0044   1380.948   1.922     1.338     1.468      -.354       25.25       30.06        1.097        YES
  8    1.4560     .0047   1575.780   2.182     5.844     7.313       .090       18.88       16.68        1.251        YES


 E/E  ( 106  TO  107 )
 T/EA ( 201  TO  202 )    T/EB ( 220  TO  221 )

  2    1.4525     .0032    397.021    .567     2.290     2.039       .026       69.04       24.06         .891        NO
  3    1.4522     .0036    594.437    .920      .409      .376      -.005      204.66      132.37         .918        NO


 E/E  ( 108  TO  109 )
 T/EA ( 203  TO  204 )    T/EB ( 213  TO  214 )

  3    1.4518     .0039    594.329    .987      .412      .379      -.010      203.52      131.66         .920        NO
  4    1.4519     .0041    790.552   1.330      .962      .938      -.003       67.68       70.19         .975        NO
```

RUN # 14
DATA REDUCTION

E/E (151 TO 154)
T/EA (205 TO 208) T/EB (215 TO 218)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
5	1.4517	.0038	986.551	1.465	.559	.605	.038	42.47	66.59	1.081	YES
6	1.4518	.0037	1183.002	1.655	.355	.417	.026	48.79	14.36	1.174	YES
7	1.4520	.0038	1379.204	1.889	.370	.422	.020	24.63	27.23	1.141	YES
8	1.4520	.0038	1573.783	2.251	.381	.464	.017	18.32	16.01	1.217	YES

E/E (160 TO 163)
T/EA (205 TO 208) T/EB (223 TO 226)

5	1.4527	.0044	986.877	1.607	.563	.603	.040	42.21	65.85	1.073	YES
6	1.4530	.0045	1183.444	1.847	.351	.413	.034	49.39	14.57	1.177	YES
7	1.4532	.0046	1379.692	2.120	.367	.421	.021	24.84	27.21	1.150	YES
8	1.4531	.0047	1574.364	2.536	.379	.463	.018	18.44	16.04	1.224	YES

E/E (141 TO 144)
T/EA (183 TO 186) T/EB (222 TO 225)

4	1.4535	.0026	791.017	.694	.953	.938	.004	67.09	70.37	.985	NO
5	1.4545	.0038	987.672	1.126	2.190	2.150	-.362	40.05	67.59	.982	NO
6	1.4546	.0040	1184.286	.990	1.432	1.592	.022	46.79	14.26	1.112	YES
7	1.4548	.0042	1380.736	1.463	1.428	1.466	-.350	23.67	27.91	1.027	YES

RUN # 14
DATA REDUCTION

E/E (37 TO 41)
T/EA (57 TO 61) T/EB (65 TO 69)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
3	1.6633	.0023	614.755	.016	.243	.237	-.012	142.35	196.04	.975	NO
4	1.6636	.0020	817.627	.017	2.434	2.527	.012	61.06	59.43	1.038	YES
5	1.6636	.0019	1020.260	.051	1.429	1.530	.008	45.11	63.41	1.071	YES
6	1.6637	.0019	1222.684	.093	.776	.846	.000	51.23	61.84	1.090	YES
7	1.6639	.0018	1426.408	.261	2.073	2.507	.015	37.75	40.18	1.209	YES

E/E (44 TO 48)
T/EA (57 TO 61) T/EB (73 TO 77)

3	1.6641	.0017	614.751	.013	.243	.239	-.014	142.41	196.74	.981	NO
4	1.6643	.0015	817.620	.017	2.438	2.553	-.040	60.94	59.82	1.047	YES
5	1.6644	.0014	1020.250	.043	1.401	1.531	.008	46.02	64.62	1.092	YES
6	1.6644	.0013	1222.673	.086	.774	.845	.002	51.34	61.91	1.091	YES
7	1.6646	.0012	1426.459	.193	2.034	2.504	.020	38.48	40.94	1.231	YES

E/E (16 TO 19)
T/EA (51 TO 54) T/EB (74 TO 77)

4	1.6606	.0061	817.610	.011	2.452	2.561	-.023	60.72	59.48	1.044	YES
5	1.6607	.0061	1020.235	.018	1.396	1.532	.011	46.17	64.84	1.097	YES
6	1.6607	.0061	1222.617	.086	.735	.847	.006	54.20	65.21	1.152	YES
7	1.6609	.0060	1426.455	.200	.517	.629	.011	38.17	40.30	1.218	YES

E/E (10 TO 13)
T/EA (51 TO 54) T/EB (66 TO 69)

4	1.6600	.0065	817.608	.014	2.450	2.536	.028	60.78	59.03	1.035	YES
5	1.6601	.0064	1020.232	.007	1.398	1.532	.011	46.10	64.81	1.096	YES
6	1.6603	.0064	1222.615	.096	.736	.848	.004	54.13	65.20	1.152	YES
7	1.6603	.0064	1426.451	.208	.519	.630	.009	37.97	40.11	1.213	YES

E/E (20 TO 25)
T/EA (56 TO 61) T/EB (72 TO 77)

2	1.6609	.0059	410.584	.004	1.404	1.336	-.019	77.39	24.31	.952	NO
3	1.6611	.0060	614.745	.005	.253	.239	-.014	136.68	188.82	.942	NO
4	1.6611	.0059	817.613	.010	2.448	2.553	-.040	60.70	59.58	1.043	YES
5	1.6612	.0058	1020.237	.024	1.395	1.531	.008	46.23	64.91	1.097	YES
6	1.6612	.0058	1222.619	.085	.733	.845	.002	54.19	65.35	1.152	YES
7	1.6614	.0057	1426.457	.195	2.052	2.504	.020	38.14	40.58	1.220	YES

RUN # 14
DATA REDUCTION

E/E (20 TO 25)
T/EA (56 TO 61)   T/EB (64 TO 69)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.6607	.0058	410.585	.003	1.408	1.331	-.010	77.16	24.38	.945	NO
3	1.6608	.0058	614.747	.006	.253	.237	-.012	136.89	188.52	.938	NO
4	1.6609	.0057	817.616	.005	2.438	2.527	.012	60.95	59.33	1.037	YES
5	1.6610	.0057	1020.240	.022	1.395	1.530	.008	46.20	64.94	1.097	YES
6	1.6611	.0057	1222.623	.090	.734	.846	.000	54.16	65.38	1.153	YES
7	1.6612	.0056	1426.458	.197	2.052	2.507	.015	33.13	40.59	1.221	YES

RUN # 15
DATA REDUCTION

E/E (13 TO 18)
T/EA (45 TO 50)   T/EB (59 TO 64)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5326	.0034	405.048	.152	1.599	1.768	-.017	59.63	21.13	1.106	YES
3	1.5324	.0036	606.308	.242	1.142	1.282	-.005	124.10	22.44	1.123	YES
4	1.5323	.0038	806.591	.360	.553	.705	.055	78.19	8.87	1.276	YES
5	1.5323	.0038	1007.033	.528	.510	.480	.030	105.56	5.69	.941	NO
6	1.5324	.0039	1208.020	.438	1.569	1.645	.030	41.90	5.18	1.048	YES
7	1.5325	.0038	1408.867	.761	4.490	6.115	.174	16.48	4.94	1.362	YES

E/E (20 TO 25)
T/EA (52 TO 57)   T/EB (65 TO 70)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5327	.0038	405.094	.180	1.601	1.784	-.020	59.70	21.23	1.115	YES
3	1.5327	.0037	606.386	.277	.279	.320	-.002	126.97	22.99	1.147	YES
4	1.5327	.0038	806.677	.404	.544	.693	.028	79.37	9.05	1.275	YES
5	1.5327	.0038	1007.165	.551	.507	.464	-.011	105.20	5.74	.915	NO
6	1.5328	.0038	1208.170	.484	1.567	1.644	.031	41.97	5.19	1.049	YES
7	1.5327	.0039	1409.063	.807	4.477	6.117	.061	16.52	4.95	1.366	YES

E/E (27 TO 32)
T/EA (45 TO 50)   T/EB (59 TO 64)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5328	.0036	405.094	.217	1.780	1.768	-.017	53.55	18.98	.993	NO
3	1.5318	.0027	606.295	.224	1.179	1.282	-.005	120.26	21.75	1.088	YES
4	1.5312	.0022	806.495	.231	.572	.705	.055	75.61	8.58	1.234	YES
5	1.5306	.0014	1006.756	.190	.360	.480	.030	149.40	8.05	1.332	YES
6	1.5302	.0007	1207.623	.141	1.208	1.645	.030	54.42	6.73	1.362	YES
7	1.5299	.0001	1408.177	.294	3.788	6.115	.174	19.54	5.86	1.614	YES

E/E (33 TO 38)
T/EA (52 TO 57)   T/EB (65 TO 70)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5305	.0007	404.965	.014	1.704	1.784	-.020	56.06	19.94	1.047	YES
3	1.5305	.0006	606.222	.052	.289	.320	-.002	122.80	22.24	1.109	YES
4	1.5299	.0002	806.305	.180	.578	.693	.028	74.63	8.51	1.199	YES
5	1.5297	.0005	1006.619	.278	.356	.464	-.011	150.06	8.18	1.305	YES
6	1.5296	.0006	1207.538	.432	1.201	1.644	.031	54.77	6.77	1.369	YES
7	1.5295	.0006	1408.230	.467	3.747	6.117	.061	19.74	5.92	1.632	YES

E/E (39 TO 44)
T/EA (45 TO 50)   T/EB (59 TO 64)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	>1
2	1.5298	.0008	404.888	.075	1.664	1.768	-.017	57.29	20.31	1.063	YES
3	1.5296	.0005	606.060	.109	1.167	1.282	-.005	121.50	21.97	1.099	YES
4	1.5294	.0003	806.225	.188	.567	.705	.055	76.22	8.65	1.244	YES
5	1.5294	.0003	1006.559	.224	.352	.480	.030	153.04	8.25	1.365	YES
6	1.5296	.0002	1207.516	.285	1.191	1.645	.030	55.19	6.82	1.381	YES
7	1.5297	.0003	1408.192	.278	3.742	6.115	.174	19.78	5.93	1.634	YES

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                                   RUN # 15
                                DATA REDUCTION

E/E  ( 77  TO  82 )
T/EA ( 167  TO  172 )    T/EB ( 159  TO  164 )

        T         r        F        r       STr       STu      Ua - Ub      S(A)       S(B)      STu/STr    >1
       avg                avg                         avg
MODE   (K)       (K)      (Hz)     (Hz)     (uK)      (uK)      (uK)       (V/K)      (V/K)
----------------------------------------------------------------------------------------------------------------
  2   1.9585    .0060   357.331   2.375    1.168     1.101     -.041       58.73      45.92        .943    NO
  3   1.9585    .0059   534.768   3.591     .543      .540      .019      158.53      11.79        .994    NO
  4   1.9585    .0059   710.752   4.703     .395      .406      .006      218.15      16.22       1.027    YES
  5   1.9586    .0058   887.750   5.698     .498      .508      .001      168.46      24.68       1.020    YES
  6   1.9587    .0058  1065.346   6.896     .596      .513     -.002      106.30       9.61        .861    NO
  7   1.9587    .0057  1241.989   8.127    2.111     2.446     -.351       40.55       9.15       1.158    YES


E/E  ( 84  TO  89 )
T/EA ( 167  TO  172 )    T/EB ( 159  TO  164 )

  2   1.9588    .0056   357.200   2.191    1.164     1.101     -.041       58.94      46.09        .946    NO
  3   1.9588    .0055   534.541   3.271     .542      .540      .019      158.78      11.80        .996    NO
  4   1.9589    .0054   710.460   4.291     .396      .406      .006      217.76      16.19       1.025    YES
  5   1.9589    .0054   887.388   5.188     .495      .508      .001      169.66      24.85       1.027    YES
  6   1.9590    .0054  1064.930   6.309     .593      .513     -.002      106.83       9.66        .865    NO
  7   1.9590    .0053  1241.513   7.456    2.104     2.446     -.351       40.70       9.18       1.163    YES


E/E  ( 96  TO  101 )
T/EA ( 167  TO  172 )    T/EB ( 159  TO  164 )

  2   1.9592    .0050   357.008   1.921    1.241     1.101     -.041       55.30      43.24        .888    NO
  3   1.9592    .0049   534.291   2.919     .555      .540      .019      155.17      11.54        .973    NO
  4   1.9593    .0049   710.124   3.818     .396      .406      .006      217.99      16.20       1.026    YES
  5   1.9593    .0048   886.964   4.591     .478      .508      .001      175.66      25.73       1.063    YES
  6   1.9593    .0049  1064.449   5.632     .476      .513     -.002      133.05      12.03       1.077    YES
  7   1.9594    .0048  1240.953   6.666    1.826     2.446     -.351       46.89      10.58       1.340    YES


E/E  ( 102  TO  107 )
T/EA ( 167  TO  172 )    T/EB ( 159  TO  164 )

  2   1.9594    .0047   356.930   1.811    1.244     1.101     -.041       55.16      43.13        .885    NO
  3   1.9594    .0047   534.180   2.762     .551      .540      .019      156.30      11.62        .980    NO
  4   1.9594    .0047   709.975   3.609     .394      .406      .006      218.76      16.26       1.030    YES
  5   1.9595    .0046   886.770   4.317     .480      .508      .001      175.12      25.65       1.060    YES
  6   1.9595    .0046  1064.231   5.324     .475      .513     -.002      133.44      12.07       1.080    YES
  7   1.9595    .0046  1240.697   6.304    1.819     2.446     -.351       47.06      10.62       1.344    YES


E/E  ( 78  TO  82 )
T/EA ( 177  TO  181 )    T/EB ( 152  TO  156 )

  3   1.9585    .0059   534.886   3.532     .546      .546     -.007      156.76      11.92       1.000    YES
  4   1.9586    .0059   710.902   4.627     .398      .409     -.004      218.19      16.21       1.027    YES
  5   1.9586    .0059   887.938   5.604     .499      .510      .004      168.46      24.67       1.023    YES
  6   1.9587    .0058  1065.585   6.769     .596      .512     -.004      106.43       9.60        .860    NO
  7   1.9587    .0058  1242.281   7.960    2.114     2.428     -.365       40.47       9.17       1.149    YES
```

RUN # 15
DATA REDUCTION

E/E (13 TO 18)
T/EA (52 TO 57)   T/EB (65 TO 70)

MODE	T avg (K)	r (K)	F avg (Hz)	r (Hz)	STr (uK)	STu avg (uK)	Ua - Ub (uK)	S(A) (V/K)	S(B) (V/K)	STu/STr	)1
2	1.5325	.0033	405.066	.140	1.605	1.784	-.020	59.52	21.17	1.111	YES
3	1.5326	.0035	606.344	.219	.286	.320	-.002	124.01	22.46	1.120	YES
4	1.5326	.0036	806.630	.342	.553	.693	.028	78.01	8.89	1.253	YES
5	1.5326	.0036	1007.108	.474	.508	.464	-.011	104.96	5.72	.913	NO
6	1.5327	.0037	1208.101	.389	1.570	1.644	.031	41.90	5.18	1.047	YES
7	1.5326	.0037	1408.982	.698	4.486	6.117	.061	16.48	4.94	1.363	YES

E/E (27 TO 32)
T/EA (52 TO 57)   T/EB (59 TO 64)

2	1.5325	.0039	405.097	.215	1.782	1.776	-.003	53.61	18.96	.996	NO
3	1.5318	.0028	606.307	.216	.295	.321	-.003	120.17	21.76	1.086	YES
4	1.5313	.0022	806.502	.222	.571	.693	.029	75.56	8.58	1.213	YES
5	1.5307	.0014	1006.799	.130	.359	.462	-.007	148.71	8.09	1.287	YES
6	1.5303	.0006	1207.649	.148	1.208	1.645	.029	54.43	6.73	1.361	YES
7	1.5299	.0000	1408.212	.292	3.787	6.088	.118	19.53	5.86	1.608	YES

E/E (33 TO 38)
T/EA (45 TO 50)   T/EB (65 TO 70)

2	1.5308	.0004	404.963	.016	1.703	1.777	-.034	56.00	19.96	1.044	YES
3	1.5306	.0006	606.210	.067	1.153	1.281	-.003	122.89	22.22	1.111	YES
4	1.5299	.0002	806.298	.183	.579	.706	.054	74.67	8.50	1.220	YES
5	1.5296	.0005	1006.576	.284	.357	.482	.026	150.75	8.14	1.350	YES
6	1.5295	.0006	1207.513	.423	1.201	1.644	.032	54.76	6.77	1.369	YES
7	1.5294	.0006	1408.196	.469	3.748	6.144	.116	19.75	5.92	1.639	YES

E/E (39 TO 44)
T/EA (52 TO 57)   T/EB (59 TO 64)

2	1.5295	.0004	404.890	.077	1.666	1.776	-.003	57.36	20.28	1.066	YES
3	1.5295	.0004	606.072	.117	.292	.321	-.003	121.41	21.99	1.097	YES
4	1.5295	.0003	806.233	.189	.567	.693	.029	76.17	8.65	1.222	YES
5	1.5295	.0004	1006.602	.219	.350	.462	-.007	152.33	8.29	1.319	YES
6	1.5297	.0003	1207.542	.298	1.191	1.645	.029	55.20	6.82	1.380	YES
7	1.5298	.0003	1408.227	.274	3.740	6.088	.118	19.77	5.93	1.628	YES

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                                   RUN # 15
                                 DATA REDUCTION

E/E  ( 85  TO  89 )
T/EA ( 177  TO  181 )    T/EB ( 152  TO  156 )

         T         r          F         r        STr        STu       Ua - Ub       S(A)        S(B)       STu/STr       >1
        avg                  avg                            avg
MODE    (K)       (K)        (Hz)      (Hz)      (uK)       (uK)       (uK)        (V/K)       (V/K)
----------------------------------------------------------------------------------------------------------------------------
  3    1.9588    .0055     534.660    3.215      .545       .546       -.007      157.01       11.94        1.002        YES
  4    1.9590    .0054     710.609    4.217      .399       .409       -.004      217.79       16.18        1.025        YES
  5    1.9590    .0054     887.576    5.097      .495       .510        .004      169.67       24.85        1.030        YES
  6    1.9590    .0054    1065.169    6.186      .593       .512       -.004      106.96        9.65         .864        NO
  7    1.9590    .0053    1241.806    7.292     2.106      2.428       -.365       40.61        9.20        1.153        YES

E/E  ( 97  TO  101 )
T/EA ( 177  TO  181 )    T/EB ( 152  TO  156 )

  3    1.9592    .0049     534.410    2.866      .558       .546       -.007      153.44       11.67         .979        NO
  4    1.9593    .0049     710.274    3.748      .398       .409       -.004      218.02       16.20        1.026        YES
  5    1.9594    .0049     887.152    4.506      .478       .510        .004      175.66       25.73        1.066        YES
  6    1.9594    .0049    1064.688    5.514      .476       .512       -.004      133.21       12.02        1.076        YES
  7    1.9594    .0048    1241.246    6.508     1.828      2.428       -.365       46.80       10.61        1.328        YES

E/E  ( 103  TO  107 )
T/EA ( 177  TO  181 )    T/EB ( 152  TO  156 )

  3    1.9594    .0047     534.298    2.711      .554       .546       -.007      154.56       11.75         .986        NO
  4    1.9595    .0047     710.125    3.541      .397       .409       -.004      218.80       16.26        1.030        YES
  5    1.9595    .0047     886.958    4.235      .480       .510        .004      175.12       25.65        1.063        YES
  6    1.9596    .0046    1064.470    5.209      .475       .512       -.004      133.59       12.05        1.079        YES
  7    1.9596    .0046    1240.990    6.149     1.821      2.428       -.365       46.96       10.64        1.333        YES

E/E  ( 96  TO  97 )
T/EA ( 175  TO  176 )    T/EB ( 159  TO  160 )

  2    1.9592    .0050     356.984    1.941     1.247      1.111       -.022       55.58       43.02         .891        NO
  3    1.9592    .0049     534.256    2.948      .553       .536        .010      154.64       11.57         .969        NO

E/E  ( 77  TO  78 )
T/EA ( 175  TO  176 )    T/EB ( 159  TO  160 )

  2    1.9585    .0060     357.306    2.395     1.174      1.111       -.022       59.03       45.69         .947        NO
  3    1.9585    .0059     534.732    3.619      .541       .536        .010      157.99       11.83         .990        NO

E/E  ( 84  TO  85 )
T/EA ( 175  TO  176 )    T/EB ( 159  TO  160 )

  2    1.9588    .0056     357.176    2.211     1.170      1.111       -.022       59.24       45.86         .950        NO
  3    1.9588    .0055     534.506    3.300      .541       .536        .010      158.24       11.84         .991        NO
```

```
                                        RUN # 15
                                     DATA REDUCTION

E/E  ( 20  TO  25 )
T/EA ( 45  TO  50 )    T/EB ( 65  TO  70 )

         T          r         F         r        STr  -     STu      Ua - Ub      S(A)       S(B)      STu/STr      >1
        avg                  avg                            avg
MODE    (K)        (K)       (Hz)      (Hz)      (uK)       (uK)       (uK)        (V/K)      (V/K)
-------------------------------------------------------------------------------------------------------------------
  2    1.5330     .0035    405.091     .182      1.599      1.777      -.034       59.63      21.26       1.111      YES
  3    1.5328     .0037    606.374     .287      1.116      1.281      -.003      127.06      22.98       1.149      YES
  4    1.5326     .0038    806.669     .412       .544       .706       .054       79.42       9.04       1.298      YES
  5    1.5326     .0039   1007.123     .595       .510       .482       .026      105.69       5.71        .946      NO
  6    1.5326     .0039   1208.145     .509      1.567      1.644       .032       41.96       5.19       1.049      YES
  7    1.5326     .0039   1409.028     .843      4.478      6.144       .116       16.53       4.95       1.372      YES


E/E  ( 27  TO  32 )
T/EA ( 52  TO  57 )    T/EB ( 65  TO  70 )

  2    1.5327     .0038    405.112     .205      1.787      1.784      -.020       53.46      19.01        .998      NO
  3    1.5320     .0026    606.331     .201       .295       .320      -.002      120.18      21.76       1.085      YES
  4    1.5315     .0020    806.534     .219       .572       .693       .028       75.43       8.60       1.212      YES
  5    1.5309     .0013   1006.831     .153       .359       .464      -.011      148.55       8.10       1.292      YES
  6    1.5304     .0005   1207.705     .209      1.209      1.644       .031       54.42       6.73       1.360      YES
  7    1.5299    0.0000   1408.293     .393      3.785      6.117       .061       19.54       5.86       1.616      YES


E/E  ( 39  TO  44 )
T/EA ( 45  TO  50 )    T/EB ( 65  TO  70 )

  2    1.5299     .0008    404.903     .087      1.669      1.777      -.034       57.13      20.36       1.065      YES
  3    1.5298     .0006    606.085     .132      1.167      1.281      -.003      121.50      21.97       1.098      YES
  4    1.5296     .0005    806.257     .228       .568       .706       .054       76.09       8.66       1.243      YES
  5    1.5296     .0004   1006.592     .268       .352       .482       .026      152.87       8.26       1.369      YES
  6    1.5297     .0003   1207.572     .344      1.191      1.644       .032       55.19       6.82       1.380      YES
  7    1.5297     .0002   1408.273     .387      3.741      6.144       .116       19.79       5.93       1.643      YES
```

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